Digitized by the Internet Archive
in 2010 with funding from
University of Toronto

http://www.archive.org/details/proceedings188600inst

INSTITUTION

OF

MECHANICAL ENGINEERS.

PROCEEDINGS.

1886.

28095

PUBLISHED BY THE INSTITUTION,

10 Victoria Chambers, London, S.W.

The right of Publication and of Translation is reserved.

TJ
1
I 4
1886

LONDON:
PRINTED BY WILLIAM CLOWES AND SONS, LIMITED,
STAMFORD STREET AND CHARING CROSS.

CONTENTS.

1886.

PAGE

List of Past-Presidents iv

List of Officers v

List of Members vii

Articles and Bye-Laws lxxxi

Proceedings, February Meeting.—Election of New Members . . 1

Annual Report of Council 3

Election of Officers 17

Appointment of Auditor 20

Alteration in Bye-Law 20

"Autographic Test-Recorder;" by J. H. Wicksteed 27

"Tests of Iron and Steel;" by P. D. Bennett 44

"Hydraulic Buffer-Stop;" by A. A. Langley 105

Memoirs 121

Proceedings, May Meeting.—Election of New Members . . . 125

"Wheel Load in Cycles;" by J. A. Griffiths 128

"Raising a Wreck;" by T. W. Wailes 189

"Refrigerating Machinery;" by T. B. Lightfoot 201

Memoirs 261

Proceedings, August Meeting, London.—Welcome to Belgian Engineers 267

Election of New Members 270

Appointment of Treasurer 271

Address of the President 275

"Compound Locomotives in Russia;" by A. Borodin . . . 297

"Compound Locomotives in India;" by C. Sandiford . . . 355

Excursions, &c. 410

Notices of Works &c. visited 413

Memoirs 460

Proceedings, October Meeting, Leeds.—Election of New Members . 465

Nomination of Candidates for Council 466

Opening of Engineering Department of Yorkshire College . . . 468

"Triple-Expansion Marine Engines;" by R. Wyllie 473

Memoirs 532

Index to Proceedings 1886 536

Institution of Mechanical Engineers.

PAST-PRESIDENTS.

George Stephenson, 1847–48. (*Deceased* 1848.)

Robert Stephenson, F.R.S., 1849–53. (*Deceased* 1859.)

Sir William Fairbairn, Bart., LL.D., F.R.S., 1854–55. (*Deceased* 1874.)

Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S., 1856–57, 1866.

John Penn, F.R.S., 1858–59, 1867–68. (*Deceased* 1878.)

James Kennedy, 1860. (*Deceased* 1886.)

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S., 1861–62, 1869.

Robert Napier, 1863–65. (*Deceased* 1876.)

John Ramsbottom, 1870–71.

Sir William Siemens, D.C.L., LL.D., F.R.S., 1872–73. (*Deceased* 1883.)

Sir Frederick J. Bramwell, D.C.L., F.R.S., 1874–75.

Thomas Hawksley, F.R.S., 1876–77.

John Robinson, 1878–79.

Edward A. Cowper, 1880–81.

Percy G. B. Westmacott, 1882–83.

Sir Lowthian Bell, Bart., F.R.S., 1884.

Institution of Mechanical Engineers.

OFFICERS.

1886.

PRESIDENT.

JEREMIAH HEAD, ... Middlesbrough.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., ... Northallerton.
SIR FREDERICK J. BRAMWELL, D.C.L., F.R.S., ... London.
THOMAS HAWKSLEY, F.R.S., ... London.
JAMES KENNEDY, ... Liverpool.
JOHN RAMSBOTTOM, ... Alderley Edge.
JOHN ROBINSON, ... Manchester.
PERCY G. B. WESTMACOTT, ... Newcastle-on-Tyne.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., .. Manchester.

VICE-PRESIDENTS.

DANIEL ADAMSON, ... Manchester.
E. HAMER CARBUTT, ... London.
CHARLES COCHRANE, ... Stourbridge.
DAVID GREIG, ... Leeds.
RICHARD PEACOCK, M.P., ... Manchester.
JOSEPH TOMLINSON, JUN., ... London.

MEMBERS OF COUNCIL.

WILLIAM DENNY, F.R.S.E., ... Dumbarton.
BENJAMIN A. DOBSON, ... Bolton.
SIR JAMES N. DOUGLASS, ... London.
SAMUEL W. JOHNSON, ... Derby.
ALEXANDER B. W. KENNEDY, ... London.
EDWARD B. MARTEN, ... Stourbridge.
EDWARD P. MARTIN, ... Dowlais.
ARTHUR PAGET, ... Loughborough.
R. PRICE-WILLIAMS, ... London.
SIR JAMES RAMSDEN, ... Barrow-in-Furness.
E. WINDSOR RICHARDS, ... Middlesbrough.
T. HURRY RICHES, ... Cardiff.
BENJAMIN WALKER, ... Leeds.
J. HARTLEY WICKSTEED, ... Leeds.
THOMAS W. WORSDELL, ... Gateshead.

TREASURER.

HARRY LEE MILLAR.

SECRETARY.

ALFRED BACHE,
Institution of Mechanical Engineers, 10 Victoria Chambers, London, S.W.
[Telegraphic address:—*Mech, London.*]

Institution of Mechanical Engineers.

LIST OF MEMBERS,

WITH YEAR OF ELECTION.

[*Telegraph Address and Telephone No. appended within brackets.*]

1886.

HONORARY LIFE MEMBERS.

1883. Abel, Sir Frederick Augustus, C.B., D.C.L., F.R.S., Royal Arsenal, Woolwich.

1878. Crawford and Balcarres, Earl of, F.R.S., 47 Brook Street, Grosvenor Square, London, W.; Haigh Hall, Wigan; and Observatory, Dunecht, Aberdeen.

1883. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1878. Rayleigh, Lord, F.R.S., 4 Carlton Gardens, London, S.W.; and Terling Place, Witham, Essex.

1883. Trasenster, Louis, Rector of the University of Liége, 9 Quai de l'Industrie, Liége, Belgium; and Chateau de Beaufraipont, Chenée, près Liége, Belgium.

MEMBERS.

1878. Abbott, Thomas, Newark Boiler Works, Newark. [*Abbott, Newark.*]

1883. Abbott, William Sutherland, Locomotive Superintendent and Assistant Engineer, Alagoas Railway, Maceio, Brazil: (or care of George S. Abbott, 9 Disraeli Road, Upton, London, E.)

1861. Abel, Charles Denton, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C. [*Patentable, London.* 2729.]

1874. Abernethy, James, F.R.S.E., 4 Delahay Street, Westminster, S.W.

1876. Adams, Henry, 60 Queen Victoria Street, London, E.C. [*Viburnum, London.*]

1879. Adams, William, Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.

1848. Adams, William Alexander, Gaines, Worcester.

1881. Adams, William John, 35 Queen Victoria Street, London, E.C. [*Packing, London.* 1854.]

1859. Adamson, Daniel, Engineering Works, Dukinfield, near Manchester; and The Towers, Didsbury, Manchester. [*Adamson, Dukinfield.*]

1871. Adamson, Joseph, Messrs. Joseph Adamson and Co., Hyde, near Manchester. [*Adamson, Hyde.*]

1886. Adamson, Thomas Alfred, Manager, Messrs. Oswald Mordaunt and Co., Southampton.

1878. Adcock, Francis Louis, Government Land Surveyor, Post Office, Kimberley, Griqualand West, Cape Colony: (or care of William R. Adcock, 17 Rue Neuve de Berry, Havre, France.)

1851. Addison, John, Colehill Cottage, Fulham, London, S.W.

1886. Aisbitt, Matthew Wheldon, 53 Mount Stuart Square, Cardiff. [*Aisbitt, Cardiff.*]

1858. Albaret, Auguste, Engine Works, Liancourt-Rantigny, Oise, France.

1886. Albright, John Francis, Messrs. R. E. Crompton and Co., 4 Mansion House Buildings, Queen Victoria Street, London, E.C.

1885. Alderson, George Beeton, Messrs. Allen Alderson and Co., Alexandria, Egypt; The Lindens, Kew Road, R.O., Richmond, Surrey: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1881. Alexander, Edward Disney, care of Mrs. W. Hudson, Middleton Hall, Pickering.

1883. Allam, Edwin Clerk, Normanhurst, Romford.

1847. Allan, Alexander, Glen House, The Valley, Scarborough.

1875. Allan, George, New British Iron Works, Corngreaves, near Birmingham; and Corngreaves Hall, near Birmingham.

1884. Allen, Alfred Evans, 37 Wellington Street, Hull.

1881. Allen, Percy Ruskin, Woodberrie Hill, Loughton, Essex.

1884. Allen, Samuel Wesley, 65 Bute Street, Bute Docks, Cardiff.

1865. Allen, William Daniel, Bessemer Steel Works, Sheffield.

1885. Allen, William Henry, Messrs. W. H. Allen and Co., York Street Works Lambeth, London, S.E. [*Pump, London.*]

1882. Allen, William Milward, Principal Assistant Engineer, Engine Boiler and Employers' Liability Insurance Co., 12 King Street, Manchester.

1870. Alley, John, care of W. Cuningham, Moscow.

1877. Alley, Stephen, Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]

1865. Alleyne, Sir John Gay Newton, Bart., Chevin, Belper.

1884. Alleyne, Reynold Henry Newton, Messrs. Scriven and Co., Leeds Old Foundry, Marsh Lane, Leeds.

1872. Alliott, James Bingham, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1876. Allport, Charles James, Midland Grand Hotel, St. Pancras, London, N.W.

1871. Allport, Howard Aston, Dodworth Grove, Barnsley.

1884. Almond, Harry John, Cartagena and Herrerias Steam Tramways, 43 Muralla del Mar, Cartagena, Spain.

1867. Amos, James Chapman, West Barnet Lodge, Lyonsdown, Barnet.

1876. Anderson, Henry John Card, Temple Sheen, East Sheen, London, S.W.

1856. Anderson, Sir John, LL.D., F.R.S.E., Fairleigh, The Mount, St. Leonard's-on-Sea.

1881. Anderson, Joseph Liddell, Messrs. Anderson and Gallwey, Hydraulic Machine Works, Lot's Road, Chelsea, London, S.W. [*Andgall. London.*]

1884. Anderson, Samuel, General Manager, Westbury Iron Works, Westbury, Wiltshire.

1856. Anderson, William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent; Lesney House, Erith, S. O., Kent; and 3 Whitehall Place, London, S.W. [3695.]

1885. Anson, Frederick Henry, 15 Dean's Yard, Westminster, S.W.

1867. Appleby, Charles James, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C. [*Millwright, London.* 1731.]; and East Greenwich Works, London, S.E.

1874. Aramburu y Silva, Fernando, Messrs. Aramburu and Sons, Cartridge Manufacturers, Calle de la Virgen de las Azucenas, Madrid: (or care of Manuel Cardenosa, 86 Great Tower Street, London, E.C.)

1881. Archbold, Joseph Gibson, Messrs. Fawcett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool; and 176 Upper Parliament Street, Liverpool.

1874. Archer, David, Central Chambers, Corporation Street, Birmingham; and 275 Pershore Road, Birmingham.

1883. Arens, Henrique, Messrs. Arens and Irmaos, Engineering Works, Rio de Janeiro, Brazil: (or care of Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough.)

1882. Armer, James, Messrs. J. and E. Hall, Iron Works, Dartford. [*Armer, Hallford, Dartford;* or *Armer, Sidcup.*]

1859. Armitage, William James, Farnley Iron Works, Leeds.

1866. Armstrong, George, Great Western Railway, Locomotive Department, Stafford Road Works, Wolverhampton.

1882. Armstrong, George Frederick, Professor of Engineering, The University, Edinburgh.

1876. Armstrong, William, Jun., Mining Engineer, Wingate Colliery, County Durham.

1858. Armstrong, Sir William George, C.B., D.C.L., LL.D., F.R.S., Elswick, Newcastle-on-Tyne; and Cragside, Morpeth.

1870. Armstrong, William Irving, Timber Works and Saw Mills, 17 North Bridge Street, Sunderland.

1873. Arnold, David Nelson, Messrs. Willans Arnold and Co., Spanish Steel Works, Sheffield.

1879. Arrol, Thomas Arthur, Messrs. Arrol Brothers, Germiston Iron Works, Glasgow; and 18 Blythswood Square, Glasgow. [*Germiston, Glasgow.* 1080.]

1873. Ashbury, Thomas (*Life Member*), 5 Market Street, Manchester; and 215 Plymouth Grove, Manchester. [*Thomas Ashbury, Manchester.*]

1884. Ashwell, Frank, 10 Erskine Street, Leicester.

1881. Aspinall, John Audley Frederick, Chief Mechanical Engineer, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1877. Astbury, James, Smethwick Foundry, near Birmingham.

1870. Atkinson, Charles Fanshawe, Messrs. Marriott and Atkinson, Fitzalan Steel Works, Sheffield. [*Marriott's, Sheffield.* 174.]

1875. Atkinson, Edward (*Life Member*), care of Messrs. Mackenzie and Brougham, 15 Great George Street, Westminster, S.W.

1882. Aveling, Thomas Lake, Messrs. Aveling and Porter, Rochester. [*Aveling, Rochester.*]

1872. Bagshaw, Walter, Messrs. J. Bagshaw and Sons, Victoria Foundry, Batley. [*Bagshaw, Batley.*]

1865. Bailey, John, Villa des Arts, Boulogne-sur-mer, France.

1886. Bailey, William, 14 Delahay Street, Westminster, S.W.

1885. Bailey, William Henry, Albion Works, Salford, Manchester. [*Beacon, Salford.*]

1880. Baillie, Robert, Messrs. Westwood Baillie and Co., London Yard Iron Works, Poplar, London, E.

1872. Bailly, Philimond, 62 Rue de la Victoire, Paris.

1880. Bain, William Neish, Messrs. Kyle and Bain, Hong Kong Ice Works, Eastpoint, Hong Kong, China; 54 St. Enoch Square, Glasgow; and Collingwood, 7 Aytoun Road, Pollockshields, Glasgow. [*Glacis, Glasgow.*]

1873. Baird, George, St. Petersburg; and 13 Berkeley Square, London, W.

1875. Bakewell, Herbert James, Engineer, Department of the Controller of the Navy, Admiralty, Whitehall, London, S.W.

1877. Bale, Manfred Powis, Appold Street, Finsbury, London, E.C.

1884. Balmokand, Lala, Executive Engineer, Public Works Department, Punjaub, India; care of Lala Shamba Das, Said Mitha, Lahore, India.

1879. Banderali, David, Assistant Locomotive and Carriage Superintendent, Chemin de fer du Nord, Paris.

1885. Barker, Tom Birkett, Scholefield Street, Birmingham.

1884. Barlow, Elias, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1882. Barlow, Henry Bernoulli, 4 Mansfield Chambers, 17 St. Ann's Square, Manchester. [*Monopoly, Manchester.*]

1875. Barlow, William Henry, F.R.S., 2 Old Palace Yard, Westminster, S.W.

1880. Barlow-Massicks, Thomas, Millom Iron Works, Millom, Cumberland.

1881. Barnett, John Davis, Mechanical Superintendent, Midland Railway, Port Hope, Ontario, Canada.

1884. Barr, Archibald, Professor of Engineering, Yorkshire College, Leeds.

1878. Barr, James, care of William McConnell, 45 Oakshaw Street, Paisley.

1883. Barras, Harry Haywood, Locomotive Superintendent, Southern Brazilian Rio Grande do Sul Railway, Rio Grande do Sul, Brazil; (or care of George Thomas Barras, 7 Howard Street, Rotherham.)

1879. Barratt, Samuel, Engineer and Manager, Corporation Gas Works, Rochdale Road Station, Manchester.

1882. Barrett, John James, Sewlal Motilal Cotton Mill, Tardeo, Bombay.

1885. Barrie, William, Outside Superintendent Engineer, Nippon Yusen Kaisha Steam Ship Co., Yokohama, Japan.

1862. Barrow, Joseph, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1867. Barrows, Thomas Welch, Messrs. Barrows and Stewart, Portable Engine Works, Banbury. [*Barrows, Banbury.*]

1871. Barry, John Wolfe, 23 Delahay Street, Westminster, S.W. [*Wolfebarry, London.* 3024.]

1883. Bartlett, James Herbert, Standard Building, Montreal, Canada.

1883. Bastin, Edwin Philp, Alliance Engineering Works, West Drayton, near Uxbridge.

1885. Bateman, Henry, Superintending Engineer, Rangoon Tramways, Rangoon, India.

1860. Batho, William Fothergill, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Othniel, London.* 3138.]

1881. Bawden, William, Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.

1872. Bayliss, Thomas Richard, Adderley Park Rolling Mills and Metal Works, Birmingham; and Belmont, Northfield, Birmingham.

1877. Beale, William Phipson, 12 Old Square, London, W.C.; and 19 Upper Phillimore Gardens, Kensington, London, W.

1881. Beattie, Alfred Luther, Manager, New Zealand Railway Workshops, Dunedin, Otago, New Zealand.

1882. Beattie, Frank, Queen Chambers, 88 Colmore Row, Birmingham. [*Beatties, Birmingham.*]

1880. Beaumont, William Worby, 163 Strand, London, W.C.

1859. Beck, Edward (*Life Member*), Dallam Forge, Warrington; and Springfield, Warrington.

1873. Beck, William Henry, 115 Cannon Street, London, E.C.

1875. Beckwith, John Henry, Manager, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester.

1882. Bedson, Joseph Phillips, Messrs. Richard Johnson and Nephew, Bradford Iron Works, Manchester.

1875. Beeley, Thomas, Engineer and Boiler Maker, Hyde Junction Iron Works, Hyde, near Manchester. [*Beeley, Hyde.*]

1884. Beetlestone, George John, 94 St. Mary's Street, Cardiff.

1885. Bell, Charles Lowthian, Clarence Iron Works, Middlesbrough.

1858. Bell, Sir Lowthian, Bart., F.R.S., Clarence Iron Works, Middlesbrough; Rounton Grange, Northallerton; Reform Club, Pall Mall, London, S.W.; and care of the Hon. E. Lyulph Stanley, 82 Harley Street, London, W. [*Sir Lowthian Bell, Middlesbrough.*]

1880. Bell, William Henry, Consulato Brittanico, Spezia, Italy; and care of Sir W. G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1879. Bellamy, Charles James, 6 Wetherby Terrace, Earl's Court, South Kensington, London, S.W.

1868. Belliss, George Edward, Steam Engine and Boiler Works, Ledsam Street, Birmingham. [*Belliss, Birmingham.*]

1878. Belsham, Maurice, Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.

1880. Benham, Percy, Messrs. Benham, 66 Wigmore Street, London, W. [*Benham, London.* 7065.]

1878. Berrier-Fontaine, Marc, Ingénieur de la Marine, Toulon Dockyard, Toulon, France: (or care of Messrs. P. S. King and Son, Canada Buildings, King Street, Westminster, S.W.) [*Berrier, Toulon.*]

1861. Bessemer, Sir Henry, F.R.S., Denmark Hill, London, S.E.

1866. Bevis, Restel Ratsey, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead; and Manor Hill, Birkenhead.

1870. Bewlay, Hubert, Birmingham Heath Boiler Works, Spring Hill, Birmingham.

1882. Bewley, Thomas Arthur, Messrs. Bewley Webb and Co., Port of Dublin Ship Yard, Dublin.

1885. Bicknell, Arthur Channing, 42 Pelham Street, South Kensington, London, S.W.

1883. Bicknell, Edward, Locomotive Superintendent, La Guaira and Caracas Railway, Venezuela; and 8 Canynge Square, Clifton, Bristol.

1884. Bika, Léon Joseph, Locomotive Engineer-in-Chief, Belgian State Railway, 29 Rue des Palais, Bruxelles, Belgium.

1877. Birch, Robert William Peregrine, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1847. Birley, Henry, 6 Brentwood, Pendleton, R.O., Manchester.

1875. Bisset, William Harvey, Board of Trade Office, Falmouth; and Erin Lodge, Green Bank, Falmouth.

1879. Black, William, Messrs. Black Hawthorn and Co., Gateshead. [*Blackthorn, Newcastletyne.*]

1862. Blake, Henry Wollaston, F.R.S., Messrs. James Watt and Co., 90 Leadenhall Street, London, E.C.

1886. Blandford, Thomas, Corbridge, R.S.O., Northumberland.

1881. Blechynden, Alfred, 20 Holly Avenue, Newcastle-on-Tyne.

1867. Bleckly, John James, Bewsey Iron Works, Warrington; and Daresbury Lodge, Altrincham.

1882. Blundstone, Samuel Richardson, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1881. Boequet, William, North Western Railway, Kurrachee, India.

1883. Bodden, George, Messrs. William Bodden and Son, Hargreaves Spindle and Flyer Works, Oldham.

1863. Boeddinghaus, Julius, Electrotechniker, Düsseldorf, Germany.

1884. Bone, William Lockhart, Works of the Ant and Bee, West Gorton, Manchester.

1880. Borodin, Alexander, Engineer-in-Chief, Russian South Western Railways, Kieff, Russia.

1885. Boughton, Henry Francis, Dan Rylands, Glass Works, Barnsley; and Hunningley, near Barnsley.

1886. Boult, Alfred Julius, Messrs. W. P. Thompson and Boult, 323 High Holborn, London, W.C.

1878. Bourdon, François Edouard, 74 Faubourg du Temple, Paris: (or care of Messrs. Negretti and Zambra, Holborn Viaduct, London, E.C.)

1884. Bourne, James Johnstone, 28 Gracechurch Street, London, E.C.

1879. Bourne, William Temple, Messrs. Bourne and Grove, Bridge Steam Saw Mills, Worcester.

1879. Bovey, Henry Taylor, Professor of Engineering, McGill University, Montreal, Canada.

1880. Bow, William, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1870. Bower, Anthony, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool.

1858. Bower, John Wilkes (*Life Member*), Neston, near Chester.

1882. Bowie, Augustus Jesse, Jun., Mining and Hydraulic Engineer, P.O. Drawer 2220, San Francisco, California, United States.

1869. Boyd, William, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne. [*Wall, Newcastle-on-Tyne; Wall, Cardiff.*]

1884. Boyer, Robert Skeffington, 8 Mount Stuart Square, Cardiff.

1882. Bradley, Frederic, Clensmore Foundry, Kidderminster.

1878. Bradley, Frederick Augustus, Eldorado, Butler County, Kansas, United States.

1881. Bradley, Thomas, Wellington Foundry, Newark.

1878. Braithwaite, Charles C., 35 King William Street, London Bridge, London, E.C.

1875. Braithwaite, Richard Charles, Messrs. Braithwaite and Kirk, Crown Bridge Works, Westbromwich: and Norfolk House, Handsworth, R. O., Birmingham. [*Braithwaite, Westbromwich.*]

1854. Bramwell, Sir Frederick Joseph, D.C.L., F.R.S., 5 Great George Street, Westminster, S.W. [*Wellbram, London.* 3060.]

1885. Brearley, Benjamin J., Union Plate Glass Works, St. Helen's.

1868. Breeden, Joseph, New Mill Works, Fazeley Street, Birmingham. [*Breeden, Birmingham.*]

1883. Bricknell, Augustus Lea, Merlin Engineering Works, Brixton Rise, London, S.W.

1881. Briggs, John Henry, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and Howden.

1886. Bright, William, Manager, Teilo Tin-Plate Works, Pontardulais, R.S.O., Glamorganshire.

1865. Brock, Walter, Messrs. Denny and Brothers, Engine Works, Dumbarton.

1879. Brodie, John Shanks, Town Surveyor and Harbour Engineer, Town Hall, Whitehaven.

1852. Brogden, Henry (*Life Member*), Hale Lodge, Altrincham, near Manchester.

1884. Brook-Fox, Frederick George, Executive Engineer, Bellary Kistna State Railway, Cumbum, Madras Presidency, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1880. Brophy, Michael Mary, Messrs. James Slater and Co., 251 High Holborn, London, W.C.

1874. Brotherhood, Peter, 15 and 17 Belvedere Road, Lambeth, London, S.E.; and 94 Cromwell Road, South Kensington, London, S.W. [*Brotherhood, London.*]

1866. Brown, Andrew Betts, Messrs. Brown Brothers and Co., Rosebank Iron Works, Edinburgh.

1885. Brown, Benjamin, Widnes Foundry, Widnes.

1879. Brown, Charles, Stabilimento Armstrong, Pozzuoli, near Naples, Italy: (or care of Dr. Gardiner Brown, 9 St. Thomas' Street, London Bridge, London, S.E.)

1880. Brown, Francis Robert Fountaine, Mechanical Superintendent, Canadian Pacific Railway, Montreal, Canada.

1881. Brown, George William, Reading Iron Works, Reading.

1863. Brown, Henry, Waterloo Chambers, Waterloo Street, Birmingham.

1884. Brown, Oswald, 27 Great George Street, Westminster, S.W. [*Acqua, London.* 3054.]

1874. Browne, Tomyns Reginald, District Locomotive Superintendent, East Indian Railway, Asansol, Bengal, India: (or care of Messrs. B. Smyth and Co., 1 New China Bazaar Street, Calcutta.)

1874. Bruce, George Barclay, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1867. Bruce, William Duff, Vice-Chairman, Port Commission, Calcutta.

1873. Brunel, Henry Marc, 23 Delahay Street, Westminster, S.W. [3024.]

1870. Brunlees, Sir James, F.R.S.E., 5 Victoria Street, Westminster, S.W.

1884. Bryan, William B., Engineer, East London Water Works, Old Ford, London, E.

1873. Buckley, Robert Burton, Executive Engineer, Indian Public Works Department, Writers' Buildings, Calcutta: (or care of H. Burton Buckley, 1 St. Mary's Terrace, Paddington, London, W.)

1877. Buckley, Samuel, Messrs. Buckley and Taylor, Castle Iron Works, Oldham.

1886. Buckney, Thomas, Messrs. E. Dent and Co., 61 Strand, London, W.C.

1878. Buddicom, Harry William, 7 Penypound, Abergavenny.

1874. Buddicom, William Barber, Penbedw Hall, Mold, Flintshire.

1872. Budenberg, Arnold, Messrs. Schaeffer and Budenberg, 1 Southgate, St. Mary's Street, Manchester. [*Manometer, Manchester.* 899.]

1882. Budge, Enrique, Engineer-in-Chief, Harbour Works, Valparaiso, Chile: (or care of Messrs. Rose-Innes and Co., 90 Cannon Street, London, E.C.)

1881. Bulkley, Henry Wheeler, 149 Broadway, New York.

1884. Bullock, Joseph Henry, General Manager, Pelsall Coal and Iron Works, near Walsall.

1882. Bulmer, John, Spring Garden Engineering Works, Pitt Street, Newcastle-on-Tyne.

1884. Bunning, Charles Ziethen, Mining Engineer of the Government Coal Mines, Warora, Central Provinces, India.

1884. Bunt, Thomas, Superintendent Engineer, Kiangnan Arsenal, Shanghai, China: (or care of R. Pearce, Lanarth House, Holders Hill, Hendon, London, N.W.)

1884. Bunting, George Albert, Rio Tinto Mines, Huelva, Spain.

1885. Burder, Walter Chapman, Messrs. Messenger and Co., Loughborough.

1877. Burgess, James Fletcher, 14 Almeric Road, Clapham Junction, London, S.W.

1881. Burn, Robert Scott, Oak Lea, Edgeley Road, near Stockport.

1878. Burnett, Robert Harvey, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1878. Burrell, Charles, Jun., Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1885. Burrell, Frederick John, Messrs. Charles Burrell and Sons, St. Nicholas Works, Thetford. [*Burrell, Thetford.*]

1877. Burton, Clerke, 22 Oakfield Street, Roath, Cardiff.

1870. Bury, William, 5 New London Street, London, E.C.

1884. Butcher, Joseph John, 4 St. Nicholas' Buildings, Newcastle-on-Tyne.

1882. Butler, Edmund, Kirkstall Forge, near Leeds. [*Forge, Kirkstall.*]

1886. Cambridge, Henry, Messrs. Jacobs and Cambridge, Bute Docks, Cardiff.

1877. Campbell, Angus, Superintendent of the Government Foundry and Workshops, Roorkee, India.

1880. Campbell, Daniel, Messrs. Campbell and Schultz, 90 Cannon Street, London, E.C. [*Duke, London.* 1893.]

1869. Campbell, James, Hunslet Engine Works, Leeds. [*Engineo, Leeds.*]

1882. Campbell, John, Messrs. R. W. Deacon and Co., Kalimaas Works, Soerabaya, Java.

1882. Campos, Raphael Martinez, 598 General Lavalle, Buenos Aires, Argentine Republic.

1885. Capito, Charles Alfred Adolph, Messrs. Capito and Hardt, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.; and 7 Nygade, Copenhagen. [*Capito Hardt, London.*]

1860. Carbutt, Edward Hamer, 19 Hyde Park Gardens, London, W.

1878. Cardew, Cornelius Edward, Locomotive and Carriage Superintendent, Madras Presidency State Railways, Guntakal Junction, Madras Presidency, India: (or care of Rev. J. H. Cardew, 1 Spring Grove Villas, Cheltenham.)

1875. Cardozo, Francisco Corrêa de Mesquita (*Life Member*), Messrs. Cardozo and Irmão, Pernambuco Engine Works, Pernambuco, Brazil: (or care of Messrs. Fry Miers and Co., 8 Great Winchester Street, London, E.C.)

1878. Carlton, Thomas William, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]; and 1 Canfield Gardens, Priory Road, West Hampstead, London, N.W.

1869. Carpmael, Frederick, 57 Arlingford Road, Tulse Hill Gardens, Brixton, London, S.W.

1866. Carpmael, William, 24 Southampton Buildings, London, W.C. [*Carpmael, London.* 2608.]

1877. Carr, Robert, Resident Engineer, London and St. Katharine Docks Co., London Docks, Upper East Smithfield, London, E.

1884. Carrick, Henry, Messrs. Carrick and Wardale, Redheugh Engine Works, Gateshead; and Holly House, Gateshead. [*Wardale, Gateshead.*]

1874. Carrington, William T. H., 72 Mark Lane, London, E.C.

1877. Carter, Claude, Manager, Messrs. Hetherington and Co., Ancoats Works, Pollard Street, Manchester.

1885. Carter, Herbert Fuller, care of H. M. Carter, 1 Gresham Buildings, Basinghall Street, London, E.C.

1877. Carter, William, Manager, The Hydraulic Engineering Company, Chester.

1870. Carver, James, Lace Machine Works, Alfred Street, Nottingham.

1883. Cawley, George, "Industries" Office, 70 Market Street, Manchester.

1876. Challen, Stephen William, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1886. Chalmers, John Reid, Resident Engineer, Pentonville Prison, Caledonian Road, London, N.

1884. Chamberlain, John, Assistant Engineer, Gas Light and Coke Co.'s Tar and Liquor Works, Beckton, London, E.

1882. Chapman, Hedley, Messrs. Chapman Carverhill and Co., Scotswood Road, Newcastle-on-Tyne.

1866. Chapman, Henry, 113 Victoria Street, Westminster, S.W.; and 10 Rue Laffitte, Paris.

1878. Chapman, James Gregson, Messrs. Fawcett Preston and Co., Phœnix Foundry, Liverpool; and 25 Austinfriars, London, E.C. [*Fawcett, London.*]

1885. Chapman, John, Engineer, Windsor and Eton Water Works, Eton.

1885. Charnock, George Frederick, Engineering Department, Technical College, Bradford.

1877. Chater, John, Messrs. Henry Pooley and Son, 89 Fleet Street, London, E.C.

1872. Chatwin, Thomas, Victoria Works, Great Tindal Street, Ladywood, Birmingham. [*Chatwin, Birmingham.*]

1873. Cheesman, William Talbot, Hartlepool Rope Works, Hartlepool.

1881. Chilcott, William Winsland, Devonport Dockyard, Devonport.

1883. Childe, Rowland, Mining Engineer, Stamp Office Place, Wakefield. [*Childe, Wakefield.*]

1877. Chisholm, John, Messrs. William Muir and Co., Sherborne Street, Manchester; and 30 Devonshire Street, Higher Broughton, Manchester.

1886. Chittenden, Edmund Barrow, Messrs. Chittenden Knight and Co., Sittingbourne; and Manor House, Offham, West Malling, near Maidstone.

1857. Chrimes, Richard, Messrs. Guest and Chrimes, Brass Works, Rotherham.

1880. Churchward, George Dundas, Box 717, General Post Office, Sydney, New South Wales; or care of A. W. Churchward, London Chatham and Dover Railway, Queenborough Pier, Queenborough; and Kearsney Manor, near Dover.

1871. Clark, Christopher Fisher, Mining Engineer, Garswood Coal and Iron Co., Park Lane Collieries, Wigan; and Cranbury Lodge, Park Lane, Wigan. [*Park Lane, Wigan.*]

1878. Clark, Daniel Kinnear, 8 Buckingham Street, Adelphi, London, W.C.

1867. Clark, George, Southwick Engine Works, near Sunderland.

1869. Clark, William, Mining Engineer, Teversall Collieries, near Mansfield.

1865. Clarke, John, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1869. Clarke, William, Messrs. Clarke Chapman and Gurney, Victoria Works, South Shore, Gateshead.

1870. Clayton, Nathaniel, Messrs. Clayton and Shuttleworth, Stamp End Iron Works, Lincoln. [*Claytons, Lincoln.*]

1886. Clayton, Samuel, St. Thomas' Engine Works, Sunbridge Road, Bradford.

1882. Clayton, William Wikeley, Messrs. Hudswell Clarke and Co., Railway Foundry, Jack Lane, Leeds. [*Loco, Leeds.* 504.]

1871. Cleminson, James, 7 Westminster Chambers, Victoria Street, Westminster, S.W. [*Cleminson, London.* 3046.]

1873. Clench, Frederick, Messrs. Robey and Co., Globe Iron Works, Lincoln. [*Robey, Lincoln.*]

1885. Close, John, Jun., York Engineering Works, Leeman Road, York.

1885. Clutterbuck, Herbert, 3 Westbourne Grove, Redcar.

1882. Coates, Joseph, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1883. Coath, David Decimus, Agricultural Implement Works and Saw Mill, Rangoon, British Burmah, India.

1881. Cochrane, Brodie, Mining Engineer, Aldin Grange, Durham.

1858. Cochrane, Charles, Woodside Iron Works, near Dudley; and Green Royde, Pedmore, near Stourbridge.

1885. Cochrane, John, Grahamston Foundry and Engine Works, Barrhead, near Glasgow. [*Cochrane, Barrhead.*]

1869. Cochrane, Joseph Bramah, Woodside Iron Works, near Dudley.

1868. Cochrane, William, Mining Engineer, Elswick Colliery, Elswick, Newcastle-on-Tyne; and Oakfield House, Gosforth, Newcastle-on-Tyne.

1867. Cockey, Francis Christopher, Selwood Iron Works, Frome.

1864. Coddington, William, M.P., Ordnance Cotton Mill, Blackburn; and Wycollar, Blackburn.

1876. Coe, William John, 1 Rumford Place, Liverpool.

1847. Coke, Richard George, Mining Engineer, 39 Holywell Street, Chesterfield; and Brimington Hall, near Chesterfield.

1884. Cole, Charles, Messrs. Cole Marchent and Co., Prospect Foundry, Bowling, near Bradford; and Kirkdale Villa, Leytonstone, London, E.

1878. Cole, John William, Messrs. James Martin and Co., Phœnix Foundry, Gawler, South Australia: (or care of J. C. Lanyon, 27 Gresham House, Old Broad Street, London, E.C.)

1878. Coles, Henry James, Sumner Street, Southwark, London, S.E.

1886. Coles, Robert, White Hall, Foleshill, Coventry.

1877. Coley, Henry, Mansion House Chambers, Queen Victoria Street, London, E.C.

1884. Collenette, Ralph, Egerton Iron Works, Chester.

1884. Colquhoun, James, General Manager, Tredegar Iron Coal and Steel Works, Tredegar.

1884. Coltman, John Charles, Messrs. Huram Coltman and Son, Engineering Works, Meadow Lane, Loughborough.

1878. Colyer, Frederick, 18 Great George Street, Westminster, S.W.

1881. Compton-Bracebridge, John Edward, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1874. Conyers, William, Engineer, Bluff Harbor Board, Campbelltown, Otago, New Zealand.

1877. Cooper, Arthur, North Eastern Steel Co., Royal Exchange, Middlesbrough.

1883. Cooper, Charles Friend, Messrs. Paterson and Cooper, Telegraph Works, Pownall Road, Dalston, London, E. [*Patella, London.* 1140.]

1877. Cooper, George, 11 Waterloo Place, Leamington.

1874. Cooper, William, Neptune Foundry, Hull. [*Cooperco, Hull.*]

1881. Coote, Arthur, Messrs. R. and W. Hawthorn Leslie and Co., Hebburn, Newcastle-on-Tyne.

1881. Copeland, Charles John, Messrs. Westray Copeland and Co., Barrow-in-Furness. [*Engine, Barrow-in-Furness.*]

1885. Coppée, Evence, 223 Avenue Louise, Bruxelles, Belgium.

1884. Corder, George Alexander, Chief Engineer, Chinese Naval Service, China; care of Commissioner of Customs, Shanghai, China.

1878. Cornes, Cornelius, 6 Norfolk Crescent, Bath, [*Stothert, Cornes, Bath.*]; and 30 Walbrook, London, E.C. [*Stothert, Cornes, London.*]

1848. Corry, Edward, 9 New Broad Street, London, E.C.

1881. Cosser, Thomas, McLeod Road Iron Works, Kurrachee, India: (or care of Messrs. Ironside Gyles and Co., 1 Gresham Buildings, Guildhall, London, E.C.)

1884. Cotton, John, Messrs. E. Ripley and Sons, Bowling Dye Works, Bradford.
1875. Cottrill, Robert Nivin, Beehive Works, Bolton. [*Beehive, Bolton.*]
1868. Coulson, William, Mining Engineer, 32 Crossgate, Durham; and Shamrock House, Durham.
1878. Courtney, Frank Stuart, 3 Whitehall Place, London, S.W.; and Palace Chambers, 9 Bridge Street, Westminster, London, S.W.
1882. Courtney, William McDougall, care of Frank S. Courtney, Palace Chambers, 9 Bridge Street, Westminster, London, S.W.
1875. Coward, Edward, Messrs. Melland and Coward, Cotton Mills and Bleach Works, Heaton Mersey, near Manchester.
1875. Cowen, Edward Samuel, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham; and 9 The Ropewalk, Nottingham. [*Cowen, Nottingham.* 87.]
1870. Cowen, George Roberts, 9 The Ropewalk, Nottingham. [286.]
1880. Cowper, Charles Edward, 6 Great George Street, Westminster, S.W.
1847. Cowper, Edward Alfred, 6 Great George Street, Westminster, S.W.
1878. Coxhead, Frederick Carley, 27 Leadenhall Street, London, E.C.
1883. Crampton, George, 4 Victoria Street, Westminster, S.W.
1847. Crampton, Thomas Russell, 4 Victoria Street, Westminster, S.W.
1882. Craven, John, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1871. Craven, Joseph, Messrs. Smith Beacock and Tannett, Victoria Foundry, Leeds.
1866. Craven, William, Vauxhall Iron Works, Osborne Street, Manchester.
1884. Crighton, John, Messrs. J. and R. Crighton, Helena Street, Ancoats, Manchester.
1873. Crippin, Edward Frederic, Mining Engineer, Brynn Hall Colliery, Ashton, near Wigan.
1883. Croft, Henry, Chemainus, Vancouver Island.
1878. Crohn, Frederick William, 16 Burney Street, Greenwich, S.E.
1877. Crompton, Rookes Evelyn Bell, Arc Works, Chelmsford; and Mansion House Buildings, Queen Victoria Street, London, E.C. [*Crompton, Chelmsford.*]
1884. Crook, Charles Alexander, Telegraph Construction and Maintenance Works, Enderby's Wharf, East Greenwich, London, S.E.
1883. Cropper, Henry S., Minerva Works, Alfred Street North, Nottingham.
1881. Crosland, James Foyell Lovelock, Chief Assistant Engineer, Boiler Insurance and Steam Power Co., 67 King Street, Manchester.
1865. Cross, James, Messrs. John Hutchinson and Co., Alkali Works, Widnes; and Ditton Lodge, Warrington.
1882. Cross, William, Messrs. R. and W. Hawthorn Leslie and Co., St Peter's Works, Newcastle-on-Tyne.

1871. Crossley, William, 153 Queen Street, Glasgow. [*Crossley, Glasgow.* 584.]

1875. Crossley, William John, Messrs. Crossley Brothers, Great Marlborough Street, Manchester. [*Crossleys, Openshaw.*]

1882. Cruickshank, William Douglass, Chief Government Engineer Surveyor, Marine Board, Sydney, New South Wales.

1886. Cryer, Thomas, Mechanical Engineering Department, Manchester Technical School, Princess Street, Manchester; and Flixton, near Manchester.

1875. Curtis, Richard, Messrs. Curtis Sons and Co., Phœnix Works, Chapel Street, Manchester. [*Curtius, Manchester.*]

1876. Cutler, Samuel, Providence Iron Works, Millwall, London, E. [*Cutler, Millwall.* 5059.]

1864. Daglish, George Heaton, St. Helen's Foundry, St. Helen's, Lancashire. [*Daglish, St. Helen's.*]

1883. D'Albert, Charles, Messrs. Hotchkiss and Co., 6 Route de Gonesse, St. Denis, near Paris; and 16 Rue des Chesneaux, Montmorency, Seine-et-Oise, France.

1886. Dale, Thomas, Messrs. James and Thomas Dale, Townsend Foundry, Kirkcaldy.

1881. D'Alton, Patrick Walter, London Mutual Boiler Insurance Co., 17 Queen Victoria Street, London, E.C.

1866. Daniel, Edward Freer, Messrs. Worthington and Co., The Brewery, Burton-on-Trent; and 89 Derby Street, Burton-on-Trent.

1866. Daniel, William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds; and Oxford House, Horsforth, Leeds.

1878. Darwin, Horace (*Life Member*), The Orchard, Huntingdon Road, Cambridge.

1873. Davey, Henry, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds. [*Sun Foundry, Leeds.*]

1883. Davidson, George, Superintendent Engineer, Australasian Steam Navigation Co., Sydney, New South Wales.

1865. Davidson, James, Crescent Villa, Lower Eglinton Road, Plumstead.

1881. Davidson, James, Engineering Works, Cumberland Street, Dunedin, Otago, New Zealand: (or care of Messrs. Buxton Ronald and Co., 24 Basinghall Street, London, E.C.)

1884. Davidson, James Young, Manager, Nagpur and Chhattisgarh, and Wardha Coal State Railways, Nagpur, Central Provinces, India; (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1884. Davies, Alfred Herbert, Eskell Chambers, Market Place, Nottingham.

1881. Davies, Benjamin, Bleach Works, Adlington, near Chorley.

1880. Davies, Charles Merson, Locomotive Superintendent, Nagpur and Chhattisgarh State Railway, Nagpur, Central Provinces, India.

1885. Davies, Edward John Mines, Westinghouse Brake Company, Canal Road, York Road, London, N.; and 9 Camden Street, Oakley Square, London, N.W.

1874. Davis, Alfred, Parliament Mansions, Westminster, S.W.

1868. Davis, Henry Wheeler, 38 New Broad Street, London, E.C.

1873. Davis, John Henry, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester; and 147 Cannon Street, London, E.C.

1877. Davison, John Walter, 1 Meshansky, Banny pereoulok, Moscow, Russia: (or care of Alfred L. Sacré, 60 Queen Victoria Street, London, E.C.)

1884. Davison, Robert, Caledonian Railway, Locomotive Department, St. Rollox, Glasgow.

1873. Davy, David, Messrs. Davy Brothers, Park Iron Works, Sheffield.

1874. Davy, Walter Scott, Silverdale, Dore, near Sheffield.

1883. Daw, James Gilbert, Messrs. Nevill Druce and Co., Llanelly Copper Works, Llanelly.

1874. Daw, Samuel, Ivy Tor, 15 Westhouse Road, Penarth.

1879. Dawson, Bernard, 110 Cannon Street, London, E.C. [*Crocus, London.*]; and The Laurels, Malvern Link, Malvern. [*Heather, Malvern Link.*]

1869. Day, St. John Vincent, 115 St. Vincent Street, Glasgow.

1886. Dayson, William Ogden, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1874. Deacon, George Frederick, Municipal Offices, Dale Street, Liverpool.

1880. Deacon, Richard William, Boeboetan, Clive Road, Penarth.

1883. Dean, Francis Winthrop, East Taunton, Massachusetts, United States.

1868. Dean, William, Locomotive Superintendent, Great Western Railway, Swindon. [*Loco, Swindon.*]

1866. Death, Ephraim, Messrs. Death and Ellwood, Albert Works, Leicester.

1884. Decauville, Paul, Portable Railway Works, Petit Bourg, Seine et Oise, France. [*Decauville, Corbeil.*]

1877. Dees, James Gibson, 36 King Street, Whitehaven.

1858. Dempsey, William, 26 Great George Street, Westminster, S.W.

1882. Denison, Samuel, Jun., Messrs. Samuel Denison and Son, Old Grammar School Foundry, North Street, Leeds. [*Weigh, Leeds.* 221.]

1883. Dennis, William Frederick, 101 Leadenhall Street, London, E.C. [*Fredennis, London.* 539.]

1882. Denny, William, F.R.S.E., Messrs. William Denny and Brothers, Leven Ship Yard, Dumbarton. [*Denny, Dumbarton.*]

1880. De Pape, William Alfred Harry, Tottenham Board of Health, Coombes Croft House, High Road, Tottenham, Middlesex.

1883. Dick, Frank Wesley, Newton Steel Works, near Glasgow.

1882. Dick, Gavin Gemmell, 1 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Dickinson, John, Palmer's Hill Engine Works, Sunderland. [*Bede, Sunderland.*]

1875. Dickinson, William, Messrs. Easton and Anderson, 3 Whitehall Place, London, S.W.

1879. Dickson, John, Suffolk House, Laurence Pountney Hill, London, E.C.

1886. Dixon, Robert, Messrs. Dixon and Corbitt, Teams Hemp and Wire Rope Works, Gateshead. [*Dixon, Gateshead.*]

1883. Dixon, Samuel, Messrs. Kendall and Gent, Victoria Works, Springfield, Salford, Manchester.

1872. Dobson, Benjamin Alfred, Messrs. Dobson and Barlow, Kay Street Machine Works, Bolton. [*Dobsons, Bolton.*]

1873. Dobson, Richard Joseph Caistor, Suiker Fabriek, Kalibayor, Banjoemas, Java: (or care of Charles E. S. Dobson, 4 Chesterfield Buildings, Victoria Park, Clifton, Bristol.)

1880. Dodd, John, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1868. Dodman, Alfred, Highgate Foundry, Lynn. [*Dodman, Lynn.*]

1880. Donald, James, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay: (or care of Messrs. Fleming Wilson and Co., 24, 25, 27 Rood Lane, Fenchurch Street, London, E.C.)

1876. Donaldson, John, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W.; and Tower House, Turnham Green.

1873. Donkin, Bryan, Jun., Messrs. B. Donkin and Co., Southwark Park Road, Bermondsey, London, S.E.

1884. Donnelly, John, Assistant Locomotive Superintendent, London and South Western Railway, Nine Elms, London, S.W.; and 70 Studley Road, Clapham Road, London, S.W.

1865. Douglas, Charles Prattman, Consett Iron Works, near Blackhill, County Durham; and Parliament Street, Consett, County Durham.

1879. Douglass, Sir James Nicholas, Trinity House, London, E.C. [2242.]

1879. Douglass, William, Chief Engineer to the Commissioners of Irish Lights, Westmoreland Street, Dublin.

1879. Doulton, Bernard, Sentinel Works, Polmadie Road, Glasgow.

1857. Dove, George, Messrs. Cowans Sheldon and Co., St. Nicholas Engine and Iron Works, Carlisle; and Viewfield, Stanwix, near Carlisle.

1873. Dove, George, Jun., Redbourn Hill Iron and Coal Co., Frodingham, near Doncaster. [*Redbourn, Frodingham.*]

1866. Downey, Alfred C., Messrs. Downey and Co., Coatham Iron Works, Middlesbrough; and Post Office Chambers, Middlesbrough.

1881. Dowson, Joseph Emerson, 3 Great Queen Street, Westminster, S.W. [*Gaseous, London.*]

1886. Doxford, Charles David, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1880. Doxford, Robert Pile, Messrs. William Doxford and Sons, Pallion Shipbuilding and Engine Works, Sunderland.

1874. Dredge, James, 35 Bedford Street, Strand, London, W.C.

1886. Drummond, Dugald, Locomotive Superintendent, Caledonian Railway, St. Rollox Works, Glasgow.

1877. Dübs, Charles Ralph, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1877. Dübs, Henry John Sillars, Messrs. Dübs and Co., Glasgow Locomotive Works, Glasgow.

1885. Duckering, Charles, Water Side Works, Rosemary Lane, Lincoln.

1880. Duckham, Frederic Eliot, Engineer, Millwall Docks, London, E.

1881. Duckham, Heber, 184 Lewisham Road, London, S.E. [*Duckham, London.*]

1879. Duncan, David John Russell, Messrs. Duncan Brothers, 32 Queen Victoria Street, London, E.C. [*Doucine, London.*]; and 10 Airlie Gardens, Kensington, London, W.

1886. Duncan, Norman, Mechanical Engineer to the Municipality, Rangoon, British Burmah, India.

1870. Dunlop, James Wilkie, 39 Delancey Street, Regent's Park, London, N.W.

1881. Dunn, Henry Woodham, Knysna, Cape Colony; and care of Miss Lewis, Preswylfa, Mold.

1885. Durham, Frederick William, 27 Leadenhall Street, London, E.C. [*Oilring, London.*]

1865. Dyson, Robert, Messrs. Owen and Dyson, Rother Iron Works, Rotherham.

1880. Eager, John Edward, Messrs. William Crichton and Co., Engineering and Shipbuilding Works, Abo, Finland.

1869. Earnshaw, William Lawrence, Superintending Marine Engineer, South Eastern Railway, Folkestone.

1858. Easton, Edward, 11 Delahay Street, Westminster, S.W.

1884. Eastwood, Charles, Manager, Linacre Gas Works, Liverpool.

1875. Eaves, William, Engineer, Messrs. John Brown and Co., Atlas Steel and Iron Works, Sheffield.

1878. Eckart, William Roberts, Messrs. Salkeld and Eckart, 632 Market Street, P. O. Box 1844, San Francisco, California, United States.

1868. Eddison, Robert William, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Ede, Francis Joseph, Messrs. Ede Brothers, Silchar, Cachar, India.

1883. Edmiston, James Brown, Marine Superintending Engineer, Messrs. Hamilton Fraser and Co., K Exchange Buildings, Liverpool; and Ivy Cottage, Highfield Road, Walton, Liverpool.

1871. Edwards, Edgar James, Messrs. Morewood and Co., Woodford Iron Works, Soho, Birmingham.

1877. Edwards, Frederick, 62 Bishopsgate Street Within, London, E.C.

1880. Edwards, Robert, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1866. Elce, John, 9 Hopwood Avenue, Manchester.

1879. Ellacott, Robert Henry, Messrs. Ellacott and Co., Plymouth Foundry, Plymouth. [*Ellacott, Plymouth.* 47.]

1875. Ellington, Edward Bayzand, Hydraulic Engineering Works, Chester; and Hydraulic Engineering Co., Palace Chambers, 9 Bridge Street, Westminster, S.W.

1859. Elliot, Sir George, Bart., M.P., Houghton-le-Spring, near Fence Houses.

1883. Elliott, Henry John, Assistant Manager, Elliott's Metal Works, Selly Oak, near Birmingham. [*Elmeco, Birmingham.*]

1869. Elliott, Henry Worton, Selly Oak Works, near Birmingham. [*Elmeco, Birmingham.*]

1882. Elliott, Thomas Graham, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1880. Ellis, Oswald William, 26 George Street, Edinburgh.

1885. Elsworthy, Edward Houtson, Messrs. Richardson and Cruddas, Byculla Iron Works, Bombay, India.

1869. Elwell, Alfred, Edge Tool Works, Wood Green, Wednesbury.

1875. Elwell, Thomas, Messrs. Varrall Elwell and Middleton, 26 Avenue Trudaine, Paris.

1878. Elwin, Charles, Metropolitan Board of Works, Spring Gardens, London, S.W.

1885. Errington, William, 28 and 29 Insurance Buildings, Auckland, New Zealand. [*Refunditur, Auckland.*]

1884. Etherington, John, 39A King William Street, London Bridge, London, E.C.

1884. Evans, David, Barrow Hæmatite Steel Works, Barrow-in-Furness.

1885. Evans, Richard Kendall, Engineering Works, Sandiacre, near Nottingham.

1864. Everitt, William Edward, Messrs. Allen Everitt and Sons, Kingston Metal Works, Adderley Street, Birmingham; and Finstal, Bromsgrove.

1881. Ewen, Thomas Buttwell, Messrs. Tangye Brothers, Cornwall Works, Soho, near Birmingham.

1869. Faija, Henry, 4 Great Queen Street, Westminster, S.W.

1868. Fairbairn, Sir Andrew, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds; and 15 Portman Square, London, W.

1875. Farcot, Jean Joseph Léon, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1880. Farcot, Paul, Messrs. Farcot and Sons, Engine Works, 13 Avenue de la Gare, St. Ouen, France.

1867. Fardon, Thomas, 106 Queen Victoria Street, London, E.C.; and 63 Collingdon Street, Luton.

1881. Farrar, Sidney Howard, Messrs. Howard Farrar and Co., Port Elizabeth, South Africa; and 69 Cornhill, London, E.C.

1882. Fawcett, Thomas Constantine, Burmantofts Foundry, Leeds. [*Fawcett, Leeds.*]

1884. Fearfield, John Piggin, Lace Machine Works, Stapleford, near Nottingham; and The Ferns, Stapleford, near Nottingham. [*Fearfield, Nottingham.*]

1882. Feeny, Victor Isidore, 106 Queen Victoria Street, London, E.C.

1876. Fell, John Corry, 1 Queen Victoria Street, London, E.C.; and Excelsior Works, Old Street, London, E.C.

1877. Fenton, James, 8 Great George Street, Westminster, S.W.

1869. Fenwick, Clennell, Victoria Docks Engine Works, Victoria Docks, London, E. [*Clennell, London.*]

1870. Ferguson, Henry Tanner, Locomotive Superintendent, Punjaub Northern State Railway, Rawal Pindi, Punjaub, India; and Plumley, Bovey Tracey, near Newton Abbot.

1881. Ferguson, William, Harbour Board, Wellington, New Zealand: (or care of Montgomery Ferguson, 81 James Street, Dublin.)

1854. Fernie, John, 2032 Locust Street, Philadelphia, Pennsylvania, United States.

1866. Fiddes, Walter, Engineer, Bristol United Gas Works, Bristol.

1872. Fidler, Edward, Prescot Colliery, Prescot.

1867. Field, Edward, Chandos Chambers, 22 Buckingham Street, Adelphi, London, W.C.

1884. Fielden, Joseph Petrie, Messrs. Thomas Robinson and Son, Railway Works, Rochdale.

1874. Fielding, John, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1884. Fisher, Henry Oakden, Engineer, Taff Vale Railway, Cardiff.

1885. Fitton, Joseph, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1877. Flannery, James Fortescue, 9 Fenchurch Street, London, E.C. [2283.]

1864. Fleet, Thomas, Crown Boiler and Gasholder Works, Swan Village, Westbromwich.

1847. Fletcher, Edward, 2 Osborne Avenue, West Jesmond, Newcastle-on-Tyne.

1885. Fletcher, Edward, Messrs. William Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.

1883. Fletcher, George, Masson and Atlas Works, Litchurch, Derby.

1872. Fletcher, Herbert, Ladyshore Colliery, Little Lever, Bolton; and The Hollins, Bolton.

1867. Fletcher, Lavington Evans, Chief Engineer, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester. [*Steam Users, Manchester.*]

1872. Flower, James J. A., Messrs. James Flower and Sons, St. Mary's Chambers, St. Mary Axe, London, E.C. [*Floramour, London.* 551.]

1859. Fogg, Robert, 11 Queen Anne's Gate, Westminster, S.W.

1886. Folger, William Mayhew, Commander, United States Navy, Bureau of Ordnance, Naval Department, Washington, D.C., United States.

1877. Forbes, Daniel Walker, Smithfield Works, New Road, Blackwall, London, E.

1882. Forbes, David Moncur, Engineer, H. M. Mint, Calcutta.

1882. Forbes, William George Loudon Stuart, Superintendent of General Workshops, H. M. Mint, Calcutta.

1861. Forster, Edward, Messrs. Chance Brothers and Co., Glass Works, Spon Lane, near Birmingham.

1882. Forsyth, Robert Alexander, 28 Tunnel Terrace, Newport, Monmouthshire.

1886. Foster, Frederick, Messrs. Barnett and Foster, Niagara Works, Eagle Wharf Road, New North Road, London, N. [*Drinks, London.* 306.]

1884. Foster, John Slater, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1882. Fothergill, John Reed, Superintendent Marine Engineer, 1 Bathgate Terrace, West Hartlepool.

1877. Foulis, William, Engineer, Glasgow Corporation Gas Works, 42 Virginia Street, Glasgow.

1885. Fourny, Hector Foster, Messrs. Earle's Shipbuilding and Engineering Works, Hull.

1866. Fowler, George, Basford Hall, near Nottingham.

1847. Fowler, Sir John, K.C.M.G., 2 Queen Square Place, Westminster, S.W.

1885. Fowler, William Henry, Manchester Steam Users' Association, 9 Mount Street, Albert Square, Manchester.

1866. Fox, Sir Douglas, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1875. Fox, Samson, Leeds Forge, Leeds.

1882. Fox, William, Leeds Forge, Leeds.

1884. Frampton, Edwin, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E. [*Oxygen, London.* 8007.]

1885. Franki, James Peter, Morts Dock and Engineering Co., Morts Bay, Sydney, New South Wales: (or care of Messrs. Mort and Co., 155 Fenchurch Street, London, E.C.)

1877. Fraser, John Hazell, Messrs. Fraser Brothers, Railway Iron Works, Bromley, London, E. [*Pressure, London.* 5420.]

1876. Frost, William, Manager, Carlisle Steel and Engine Works, Sheffield; and Woodhill, Sheffield.

1866. Fry, Albert, Bristol Wagon Works, Lawrence Hill, Bristol.

1886. Fulton, Arthur Robert William, Resident Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1884. Furness, Edward, Metropolitan Buildings, 63 Queen Victoria Street, London, E.C.

1882. Furrell, Edward Wyburd, care of Paul Bakewell, 417 Olive Street, St. Louis, Missouri, United States.

1866. Galloway, Charles John, Messrs. W. and J. Galloway and Sons, Knott Mill Iron Works, Manchester. [*Galloway, Manchester.*]

1862. Galton, Capt. Douglas, C.B., R.E., F.R.S., 12 Chester Street, Grosvenor Place, London, S.W.

1880. Galwey, John Wilfrid de Villemont, Messrs. Galwey Whitehead and Co., Warrington Engine and Iron Works, Lythgoe's Lane, Warrington.

1884. Ganga Ram, Lala, Executive Engineer, Public Works Department, Amritsar, Punjaub, India.

1882. Garrett, Frank, Messrs. Richard Garrett and Sons, Leiston Works, Leiston, R.S.O., Suffolk. [*Garrett, Leiston.*]

1867. Gauntlett, William Henry, 33 Albert Terrace, Middlesbrough. [*Pyrometer, Middlesbrough.*]

1880. Geoghegan, Samuel, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin. [*Guinness, Dublin.*]

1871. Gibbins, Richard Cadbury, Berkley Street, Birmingham. [*Gibbins, Birmingham.*]

1872. Gilbert, Ebenezer Edwin, Canada Engine Works, Montreal, Canada.

1883. Gilchrist, Percy Carlyle, Palace Chambers, 9 Bridge Street, Westminster, S.W. [*Gilchrist, London.*]

1856. Gilkes, Edgar, Messrs. Thompson and Gilkes, Stockton-on-Tees; and Ingleside, Stockton-on-Tees.

1880. Gill, Charles, Messrs. Young and Gill, Engineering Works, Java; and Java Lodge, Beckenham.

1866. Gilroy, George, Engineer, Ince Hall Colliery, Wigan.

1884. Gimson, Arthur James, Messrs. Gimson and Co., Engine Works, Vulcan Street, Leicester. [*Gimson, Leicester.* 6.]

1884. Girdlestone, John Ward, Engineer, Bristol Docks, Bristol.

1881. Girdwood, William Wallace, Indestructible Packing Works, 9 Lea Place, East India Dock Road, Poplar, London, E.

1874. Gjers, John, Messrs. Gjers Mills and Co., Ayresome Iron Works, Middlesbrough.

1862. Godfrey, Samuel, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and Beaconsfield House, North Ormesby, Middlesbrough.

1880. Godfrey, William Bernard, 23 St. Swithin's Lane, London, E.C.

1882. Goldsmith, Alfred Joseph, Messrs. John Walker and Co., Union Foundry and Shipbuilding Works, Maryborough, Queensland: (or care of Messrs. James McEwan and Co., 27 Lombard Street, London, E.C.)

1879. Goldsworthy, Robert Bruce, Messrs. Thomas Goldsworthy and Sons, Britannia Emery Mills, Hulme, Manchester. [*Goldsworthy, Manchester.*]

1867. Gooch, William Frederick, Vulcan Foundry, Newton-le-Willows, Lancashire.

1884. Good, Henry, Messrs. Jardine and Co., Shanghai, China: care of Marine Engineers' Institute, Shanghai, China.

1877. Goodbody, Robert, Messrs. Goodbody, Clashawaun Jute Factory, Clara, near Moate, Ireland.

1869. Goodeve, Thomas Minchin, 5 Crown Office Row, Temple, London, E.C.

1875. Goodfellow, George Ben, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1884. Goodger, Walter William, Messrs. George Fletcher and Co., Masson and Atlas Works, Litchurch, Derby.

1885. Goodwin, Arnold, Jun., 56 Sumner Street, Southwark, London, S.E.

1865. Göransson, Göran Fredrick, Sandvik Iron Works, near Gefle, Sweden: (or care of F. W. Lonergan, 121 Cannon Street, London, E.C.)

1875. Gordon, Robert, Executive Engineer, Public Works Department, Henzada, British Burmah, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1879. Gorman, William Augustus, Messrs. Siebe and Gorman, 187 Westminster Bridge Road, London, S.E. [*Siebe, London.*]

1880. Gottschalk, Alexandre, 13 Rue Auber, Paris.

1877. Goulty, Wallis Rivers, Messrs. Wheatley Kirk, Price, and Goulty, Albert Chambers, Albert Square, Manchester. [*Indicator, Manchester.*]

1878. Grafton, Alexander, 113 Cannon Street, London, E.C.

1865. Gray, John McFarlane, Chief Examiner of Engineers, Marine Department, Board of Trade; 86 Osborn Road, Forest Gate, London, E.

1876. Gray, John William, Engineer, Corporation Water Works, Bread Street, Birmingham.

1879. Gray, Thomas Lowe, Rokesley House, St. Michael's Road, Stockwell, London, S.W.

1879. Greathead, James Henry, 8 Victoria Chambers, Victoria Street, Westminster, S.W.

1861. Green, Sir Edward, Bart., M.P., Messrs. E. Green and Son, Phœnix Works, Wakefield.

1871. Greener, John Henry, 14 St. Swithin's Lane, London, E.C.

1878. Greenwood, Arthur, Messrs. Greenwood and Batley, Albion Works, Leeds.

1874. Greenwood, William Henry, Professor of Metallurgy and Mechanical Engineering, Firth College, Sheffield.

1865. Greig, David, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds. [*Greig, Fowler, Leeds.* 155.]

1885. Greig, David, Jun., Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1880. Gresham, James, Messrs. Gresham and Craven, Craven Iron Works, Ordsal Lane, Salford, Manchester. [*Brake, Manchester.*]

1883. Grew, Frederick, Whitmore Place, 418 Coventry Road, Small Heath, Birmingham.

1874. Grew, Nathaniel, Dashwood House, 9 New Broad Street, London, E.C.

1866. Grice, Edwin James, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.

1868. Grierson, Henry Houldsworth, Moss Brow, Warburton, near Warrington.

1884. Griffiths, James E., Mount Stuart Square, Cardiff.

1873. Griffiths, John Alfred, Priory Mill, Coventry; and 2 Chester Street, Coventry.

1879. Grose, Arthur, Manager, Vulcan Iron Works, Guildhall Road, Northampton.

1886. Grove, David, 24 Friedrich Strasse, Berlin.

1870. Guilford, Francis Leaver, Messrs. G. R. Cowen and Co., Beck Works, Brook Street, Nottingham. [*Cowen, Nottingham.* 87.]

1883. Guinotte, Lucien, Mariemont and Bascoup Collieries, Mariemont, Belgium.

1884. Gulland, James Ker, Diamond Drill Co., 6A Victoria Street, Westminster, S.W. [*Gulland, London.*]

1886. Guy, Charles Williams, 17 Belsize Crescent, Hampstead, London, N.W.

1870. Gwynne, James Eglinton Anderson (*Life Member*), Essex Street Works, Strand, London, W.C. [*Gwynnegram, London.*]

1870. Gwynne, John, Hammersmith Iron Works, Hammersmith, London, W.

1879. Hadfield, Robert, Hadfield Steel Foundry Co., Attercliffe, Sheffield. [*Hadfield, Sheffield.*]

1861. Haggie, Peter, Hemp and Wire Rope Works, Gateshead.

1884. Hall, Albert Francis, George F. Blake Manufacturing Co., 44 Washington Street, Boston; and 3 Cordis Street, Charlestown, Boston, Massachusetts, United States.

1879. Hall, John Francis, Messrs. W. Jessop and Sons, Brightside Steel Works, Sheffield.

1881. Hall, John Percy, Engine Works Department, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1882. Hall, John Willim, Foundry and Engine Works, Blaydon-on-Tyne, R.S.O., County Durham.

1874. Hall, Thomas Bernard, Patent Nut and Bolt Works, Smethwick, near Birmingham; and Ingleside, Sandon Road, Edgbaston, Birmingham.

1886. Hall, William James, Harbour Engineer, Limerick, Ireland.

1871. Hall, William Silver, Messrs. Hall and Clarke, Canal Street Iron Works, Derby [*Canal, Derby.*]; and 39 Hartington Street, Derby. [*Silverhall, Derby.*]

1880. Hallett, John Harry, 120 Powell's Place, Bute Docks, Cardiff.

1871. Halpin, Druitt, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Halpin, London.*]

1875. Hammond, Walter John, Resident Engineer and Locomotive Superintendent, Paulista Railway, Jundiahy, São Paulo, Brazil; (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1886. Hanbury, John James, Resident Engineer and Locomotive Superintendent, Metropolitan Railway, Neasden, London, N.W.

1870. Hannah, Joseph Edward, Water Works, Winnipeg, Manitoba, Canada.

1874. Harding, William Bishop, Zerge-utcza 13, Budapest, Hungary.

1881. Hardingham, George Gatton Melhuish, 191 Fleet Street, London, E.C. [*Hardingham, London.*]

1883. Hardy, John George, Vacuum Brake Co., 7 Hohenstaufengasse, Vienna.

1869. Harfield, William Horatio, Mansion House Buildings, Queen Victoria Street, London, E.C.

1884. Harker, Harold Hayes, Locomotive Superintendent, Minas and Rio Railway, Cruzeiro, Rio de Janeiro, Brazil: (or care of Jesse T. Curtis, Hill Street, Poole.)

1873. Harman, Harry Jones, 22 Booth Street, Manchester.

1879. Harris, Henry Graham, 5 Great George Street, Westminster, S.W.

1885. Harris, John Henry, Worthington Pumping Engine Co., 114 Queen Victoria Street, London, E.C. [*Tuncharp, London.*]

1873. Harris, Richard Henry, 63 Queen Victoria Street, London, E.C.

1877. Harris, William Wallington, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.; and 24 Alexandra Villas, Hornsey Park, London, N.

1885. Harrison, Frederick Henry, Lincoln Malleable Iron Works, Lincoln. [*Malleable, Lincoln.*]

1885. Harrison, Joseph, Normal School of Science, South Kensington, London, S.W.

1858. Harrison, Thomas Elliot, Engineer-in-Chief, North Eastern Railway, Newcastle-on-Tyne.

1883. Hart, Frederick, Pottstown, Montgomery County, Pennsylvania, United States: (or care of A. Pye-Smith, Messrs. Samuel Osborn and Co., 16 Philpot Lane, London, E.C.)

1877. Hart, James, Summerfield, Slaughter, King Co., Washington Territory, United States.

1882. Hart, Norman, 12 Victoria Grove, Kensington, London, W.
1872. Hartnell, Wilson, Benson's Buildings, Park Row, Leeds.
1882. Harvey, Charles Randolph, Messrs. G. and A. Harvey, Albion Machine Works, Govan, near Glasgow.
1886. Harvey, John Boyd, Colorada Nitrate Co., Iquique, Chile.
1883. Harvey, Robert, Prospect Place, Truro; and Lisworney, Torquay.
1878. Harwood, Robert, Soho Iron Works, Bolton.
1882. Haskins, John Ferguson, 114A Queen Victoria Street, London, E.C.
1881. Haslam, Alfred Seale, Union Foundry, Derby. [*Zero, Derby.*]
1858. Haswell, John A., North Eastern Railway, Locomotive Department, Gateshead.
1885. Hatton, Robert James, Henley's Telegraph Works, North Woolwich, London, E.
1857. Haughton, S. Wilfred (*Life Member*), Greenbank, Carlow, Ireland.
1878. Haughton, Thomas, 110 Cannon Street, London, E.C. [*Haughnot, London.*]
1885. Haughton, Thomas James, Belmont, 70 West Hill, Sydenham, London, S.E.
1861. Hawkins, William Bailey, 39 Lombard Street, London, E.C.
1870. Hawksley, Charles, 30 Great George Street, Westminster, S.W.
1856. Hawksley, Thomas, F.R.S., 30 Great George Street, Westminster, S.W.
1873. Hay, James A. C., Superintendent of Machinery to the War Department, Royal Arsenal, Woolwich.
1882. Hayes, Edward, Watling Works, Stony Stratford. [*Hayes, Stony Stratford.*]
1879. Hayes, John, 28 Connaught Road, Harlesden, London, N.W.
1862. Haynes, Thomas John, Calpe Foundry and Forge, North Front, Gibraltar. [*Haynes, Gibraltar.*]
1880. Hayter, Harrison, 33 Great George Street, Westminster, S.W.
1869. Head, Jeremiah, Messrs. Fox Head and Co., Newport Rolling Mills, Middlesbrough. [*Head, Foxhead, Middlesbrough.* 22.]
1873. Headly, Lawrance, Exchange Iron Foundry and Implement Works, Corn Exchange Street, Cambridge; and 1 Camden Place, Cambridge. [*Vanes, Cambridge.*]
1857. Healey, Edward Charles, 163 Strand, London, W.C.
1872. Heap, William, 9 Rumford Place, Liverpool. [*Metal, Liverpool.* 809.]
1864. Heathfield, Richard, Messrs. Morewood and Co., Lion Galvanising Works, Birmingham Heath, Birmingham.
1875. Heenan, Richard Hammersley, Messrs. Heenan and Froude, Newton Heath Iron Works, near Manchester. [*Spherical, Newton Heath.*]
1879. Henchman, Humphrey, care of John Henchman, Uplands, Wallington, Surrey.
1869. Henderson, David Marr, Engineer-in-Chief, Imperial Maritime Customs Service of China, Shanghai, China.

1883. Henderson, John Baillie, Engineer to the Queensland Government, Water Supply Department, Brisbane, Queensland.

1883. Henderson, William, El Callao Mine, Cuidad, Bolivar, Venezuela, South America.

1878. Henesey, Richard, Messrs. Donald Henesey and Couper, Ripon Iron Works, Frere Road, Bombay; and 3 Beckett Terrace, Uxbridge.

1879. Henriques, Cecil Quixam, 113 Cannon Street, London, E.C.

1875. Hepburn, George, Redcross Chambers, Redcross Street, Liverpool. [*Hepburn, Liverpool.*]

1876. Heppell, Thomas, Mining Engineer, Ouston Collieries, Chester-le-Street.

1877. Hepworth, Thomas Howard, Curzon House, Curzon Street, Derby.

1884. Hernu, Arthur Henry, 113 Victoria Street, Westminster, S.W.

1884. Hervey, Matthew Wilson, Assistant Engineer, West Middlesex Water Works, Hammersmith, London, W.

1879. Hesketh, Everard, Messrs. J. and E. Hall, Iron Works, Dartford. [*Hesketh, Dartford.*]

1865. Hetherington, John Muir, Vulcan Works, Pollard Street, Manchester. [*Hethrinton, Manchester.*]

1866. Hetherington, Thomas Ridley, Vulcan Works, Pollard Street, Manchester. [*Hethrinton, Manchester.*]

1872. Hewlett, Alfred, Haseley Manor, Warwick.

1872. Hewlett, William Henry, Wigan Coal and Iron Works, Kirkless Hall, Wigan.

1871. Hick, John, Mytton Hall, Whalley, near Blackburn.

1885. Hicken, Thomas, Dunchurch, Rugby.

1864. Hide, Thomas C., 4 Cullum Street, Fenchurch Street, London, E.C.

1879. Higson, Jacob, Mining Engineer, Crown Buildings, 18 Booth Street, Manchester.

1871. Hill, Alfred C., Clay Lane Iron Works, South Bank, R.S.O., Yorkshire.

1885. Hill, Robert Anderson, Royal Mint, Little Tower Hill, London, E.

1882. Hiller, Henry, Chief Engineer, National Boiler Insurance Company, 22 St. Ann's Square, Manchester.

1873. Hilton, Franklin, Chief Engineer, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough; and South Bank, R.S.O., Yorkshire.

1876. Hind, Thomas William, Messrs. Henry Hind and Son, Central Engineering Tool Works, Queen's Road, Nottingham [*Hind, Nottingham.*]; and 62 Blackfriars Road, London, S.E.

1885. Hindmarsh, Thomas, 303 King Street West, Hammersmith, London, W.

1870. Hodges, Petronius, 238 Barnsley Road, Sheffield.

1880. Hodgson, Charles, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W.

1882. Hodson, Richard, Thames Iron Works and Shipbuilding Co., Blackwall, London, E.
1884. Hogg, William Thomas, Ram Brewery, Wandsworth, London, S.W.
1852. Holcroft, James, Red Hill House, Stourbridge.
1866. Holcroft, Thomas, Bilston Foundry, Bilston.
1886. Holden, James, Locomotive Superintendent, Great Eastern Railway, Stratford Works, London, E.
1884. Holland, Calvert Bernard, General Manager, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.
1886. Hollis, Charles William, Messrs. Ketton and Hollis, Meadow Tool Works, Mayfield Grove, Nottingham.
1885. Hollis, Henry William, General Manager, Butterley Iron Works, near Alfreton.
1883. Holroyd, John, Tomlinson Street, Hulme, Manchester. [*Knit, Manchester.*]
1863. Holt, Francis, Midland Railway, Locomotive Department, Derby.
1873. Holt, Henry Percy, The Cedars, Didsbury, Manchester.
1867. Holt, William Lyster, 17 Parliament Street, Westminster, S.W.
1867. Homer, Charles James, Mining Engineer, Ivy House, Stoke-upon-Trent.
1848. Homersham, Samuel Collett, 19 Buckingham Street, Adelphi, London, W.C.
1883. Hooton, William, Continental Lace-Machine Works, Great Eastern Street, Nottingham.
1866. Hopkins, John Satchell, Jesmond Grove, Highfield Road, Edgbaston, Birmingham.
1885. Hopkinson, Charles, Werneth Chambers, 29 Princess Street, Manchester.
1856. Hopkinson, John, Grove House, Oxford Road, Manchester.
1874. Hopkinson, John, Jun., D.Sc., F.R.S., Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham; and 4 Westminster Chambers, Victoria Street, Westminster, S.W. [3092.]
1877. Hopkinson, Joseph, Messrs. Joseph Hopkinson and Co., Britannia Works, Huddersfield.
1880. Hornsby, James, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham. [*Hornsbys, Grantham.*]
1873. Horsley, Charles, 22 Wharf Road, City Road, London, N.
1858. Horsley, William, Whitehill Point Iron Works, Percy Main, near Newcastle-on-Tyne.
1868. Horton, Enoch, Alma Works, Darlaston, near Wednesbury.
1871. Horton, George, Messrs. Horton and Son, Steam Boiler Works, 63 Park Street, Southwark, London, S.E.
1875. Hosgood, Thomas Hopkin, Richardson Street, Swansea.
1873. Hoskin, Richard, 1 East Parade, Sheffield.
1866. Houghton, John Campbell Arthur, Woodside Iron Works, near Dudley.

1864. Howard, Eliot, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1860. Howard, James, Messrs. J. and F. Howard, Britannia Iron Works, Bedford; and Clapham Park, Bedfordshire. [*Howard, Bedford.*]

1882. Howard, John William, 78 Queen Victoria Street, London, E.C.

1867. Howard, Robert Luke, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1885. Howarth, William, Manager, Oldham Boiler Works, Oldham. [*Boilers, Oldham.*]

1861. Howell, Joseph Bennett, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1877. Howell, Samuel Earnshaw, Messrs. Howell and Co., Brook Steel Works, Brookhill, Sheffield. [*Howell, Sheffield.*]

1882. Howl, Edmund, Messrs. Lee Howl Ward and Howl, Tipton. [*Howl, Tipton.*]

1877. Howlett, Francis, Messrs. Henry Clayton Son and Howlett, Atlas Works, Woodfield Road, Harrow Road, London, W. [*Brickpress, London.*]

1884. Hoyle, Frank Edward, Locomotive Superintendent, Bahia and San Francisco Railway, Periperi, Bahia, Brazil: (or care of Leonard Micklem, Secretary, Bahia and San Francisco Railway, 38 New Broad Street, London, E.C.)

1882. Hudson, John George, Messrs. Mirrlees Watson and Co., 45 Scotland Street, Glasgow.

1884. Hudson, Robert, Gildersome Foundry, near Leeds [*Gildersome, Leeds.* 14.]; and Weetwood Mount, Headingley, near Leeds. [454.]

1881. Hughes, Edward William Mackenzie, Locomotive and Carriage Superintendent, Indus Valley State Railway, Sukkur, Sindh, India: (or care of Charles William Lennox, 13 Derby Crescent, Kelvinside, N., Glasgow.)

1867. Hughes, George Douglas, Queen's Foundry, London Road, Nottingham.

1871. Hughes, Joseph, Howgate, Moresby, near Whitehaven.

1864. Hulse, William Wilson, Ordsal Tool Works, Regent Bridge, Salford, Manchester.

1880. Humphrys, James, 16 and 17 Leadenhall Buildings, London, E.C.; and Arundel House, Lancaster Road, South Norwood Park, London, S.E.

1866. Humphrys, Robert Harry, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1882. Hunt, Reuben, Aire and Calder Chemical Works, Castleford, near Normanton.

1885. Hunt, Richard, Messrs. Thomas Hunt and Sons, Albion Iron Works, 132 Bridge Road West, Battersea, London, S.W.

1856. Hunt, Thomas, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1874. Hunt, William, Alkali Works, Lea Brook, Wednesbury; Hampton House, Wednesbury; and Aire and Calder Chemical Works, Castleford, near Normanton.

1886. Hunter, John, Messrs. Campbells and Hunter, Dolphin Foundry, Saynor Road, Hunslet, Leeds.

1877. Hunter, Walter, Messrs. Hunter and English, High Street, Bow, London, E. [*Venator, London.*]

1865. Hyde, Major-General Henry, R.E. (*Life Member*), India Office, Westminster, S.W.

1885. Hyland, John Frank, Engineer to Navigation of Paulista Railway, Campinas, Sao Paulo, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1877. Imray, John, Messrs. Abel and Imray, 20 Southampton Buildings, London, W.C.

1882. Ingham, William, 22 St. Ann's Square, Manchester.

1872. Inman, Charles Arthur, Messrs. Clay Inman and Co., Birkenhead Forge, Beaufort Road, Birkenhead; and 45 North Corridor, The Albany, Liverpool.

1883. Instone, Thomas, Assistant Manager and Engineer, Elliott's Metal Works, Selly Oak, near Birmingham; and Harborne, near Birmingham.

1872. Jack, Alexander, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.

1884. Jacks, Thomas William Moseley, Patent Shaft Works, Wednesbury; and 72 Stafford Street, Wednesbury.

1859. Jackson, Matthew Murray, 47 Norton Road, West Brighton, Brighton; and care of Messrs. Howard and Pitcairn, 155 Fenchurch Street, London, E.C.

1847. Jackson, Peter Rothwell, Salford Rolling Mills, Manchester; and Blackbrooke, Pontrilas, R.S.O., Herefordshire. [*Jacksons, Manchester.*]

1873. Jackson, Samuel, C.I.E., Locomotive and Carriage Superintendent, Great Indian Peninsula Railway, Bombay.

1886. Jackson, Thomas, Yorkshire College, Leeds.

1872. Jackson, William Francis, Bowling Iron Works, near Bradford.

1873. Jacob, Edward Westley, 3 Woodside Terrace, Grange Road, Darlington.

1876. Jacobs, Charles Mattathias, 126 Bute Docks, Cardiff. [*Engineer, Cardiff.* 29.]

1878. Jakeman, Christopher John Wallace, Manager, Messrs. Merryweather and Sons, Tram Locomotive Works, Greenwich Road, London, S.E.

1877. James, Christopher, 4 Alexandra Road, Clifton, Bristol.

1877. James, John William Henry, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1879. Jameson, George, Glencormac, Bray, Ireland.

1881. Jameson, John, Messrs. Jameson and Schaeffer, Akenside Hill, Newcastle-on-Tyne. [*Jameson, Newcastle-on-Tyne.* 226.]

1876. Jebb, George Robert, Engineer to the Birmingham Canal Navigation, Birmingham; and The Laurels, Shrewsbury.

1861. Jeffcock, Thomas William, Mining Engineer, 18 Bank Street, Sheffield.

1880. Jefferies, John Robert, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.

1881. Jefferiss, Thomas, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1863. Jeffreys, Edward A., Monk Bridge Iron Works, Leeds; and Gipton Lodge, Leeds.

1877. Jeffreys, Edward Homer, 5 Westminster Chambers, Victoria Street, Westminster, S.W.

1884. Jenkins, Alfred, Sirhowy House, Romilly Road, Canton, near Cardiff.

1880. Jenkins, Rhys, Patent Office, 25 Southampton Buildings, London, W.C.

1878. Jensen, Peter, 77 Chancery Lane, London, W.C. [*Venture, London.*]

1886. Jewell, Henry William, Messrs. Jewell and Son, City Foundry, Winchester.

1863. Johnson, Bryan, Hydraulic Engineering Works, Chester; and 34 King Street, Chester.

1882. Johnson, Charles Malcolm, Chief Engineer, R.N., H. M. Ironclad "Swiftsure," Esquimalt, Vancouver Island; and 11 Napier Street, Stoke, Devonport.

1885. Johnson, John Clarke, Messrs. James Russell and Sons, Crown Tube Works, Wednesbury.

1882. Johnson, Samuel, Manager, Globe Cotton and Woollen Machine Works, Rochdale.

1861. Johnson, Samuel Waite, Locomotive Superintendent, Midland Railway, Derby.

1886. Johnson, William, Resident Engineer, West India Docks, London, E.

1872. Joicey, Jacob Gowland, Messrs. J. and G. Joicey and Co., Forth Banks West Factory, Newcastle-on-Tyne. [*Engines, Newcastle-on-Tyne.*]

1882. Jolin, Philip, 35 Narrow Wine Street, Bristol; and 2 Elmdale Road, Redland, Bristol.

1871. Jones, Charles Henry, Assistant Locomotive Superintendent, Midland Railway, Derby.

1873. Jones, Edward, Messrs. Greenwood and Batley, Albion Works, Leeds; and 13 Blenheim Square, Leeds.

1873. Jones, Edward Trygarn, Consulting Engineer to the Commercial Steam Ship Co., 32 Great St. Helen's, London, E.C.

1884. Jones, Felix, Messrs. Jones and Foster, 39 Bloomsbury Street, Birmingham.

1878. Jones, Frederick Robert, Superintending Engineer, Sirmoor State, Nahan, near Umballa, Punjaub, India: (or care of Messrs. Richard W. Jones and Co., Newport, Monmouthshire.)

1867. Jones, George Edward, Sukkur, near Karachi, Punjaub, India: (or care of Mrs. Edward Jones, 9 Sydenham Villas, Cheltenham.)

1878. Jones, Harry Edward, Engineer, Commercial Gas Works, Stepney, London, E.

1881. Jones, Herbert Edward, Locomotive Department, Midland Railway, Manchester.

1882. Jones, Samuel Gilbert, Bombay Burmah Trading Corporation, Rangoon, British Burmah: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1872. Jones, William Richard Sumption, Rajputana State Railway, Ajmeer, India: (or care of Messrs. Henry S. King and Co., 45 Pall Mall, London, S.W.)

1883. Jordan, Edward, Manager, Cardiff Junction Dry Dock and Engineering Works, Cardiff.

1884. Josse, Hippolyte, 15 Rue Drouot, Paris.

1880. Joy, David, 8 Victoria Chambers, Victoria Street, Westminster, S.W.; and Manor Road House, Beckenham.

1878. Jüngermann, Carl, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany.

1884. Justice, Howard Rudulph, 55 and 56 Chancery Lane, London, W.C. [*Syng, London.* 2504.]

1882. Keeling, Herbert Howard, Merlewood, Eltham.

1869. Keen, Arthur, Patent Nut and Bolt Works, Smethwick, near Birmingham. [*Globe, Birmingham.*]

1867. Kellett, John, Clayton Street, Wigan.

1873. Kelson, Frederick Colthurst, Angra Bank, Waterloo Park, Waterloo, near Liverpool.

1881. Kendal, Ramsey, Locomotive Department, North Eastern Railway, Gateshead.

1885. Kendall, George, Lloyd's Register of Shipping, Dock Street, Newport, Monmouthshire.

1863. Kennan, James, Messrs. Kennan and Sons, Engineering Works, Fishamble Street, Dublin. [*Kennans, Dublin.*]

1879. Kennedy, Alexander Blackie William, Professor of Engineering, University College, Gower Street, London, W.C.

1847. Kennedy, James, Gilmerton, Cressington Park, Aigburth, Liverpool.

1863. Kennedy, John Pitt, Bombay Baroda and Central Indian Railway, 45 Finsbury Circus, London, E.C.; and 29 Lupus Street, St. George's Square, London, S.W.

1868. Kennedy, Thomas Stuart, Parkhill, Wetherby.

1875. Kenrick, George Hamilton, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich; and Whetstone, Somerset Road, Edgbaston, Birmingham.

1866. Kershaw, John, 9 Duke Street, Portland Place, London, W.

1884. Kershaw, Thomas Edward, Chilvers Coton Foundry, Nuneaton.

1880. Kessler, Emil, Maschinenfabrik, Esslingen, Wurtemberg, Germany.

1885. Keydell, Amandus Edmund, Lloyd's Register of Shipping, Cardiff.

1885. Keymer, Henry John Cubitt, Fisheries Iron Works, Gorleston, Great Yarmouth.

1885. Kidd, Hector, Colonial Sugar Refining Co., Sydney, New South Wales.

1872. King, William, Engineer, Liverpool United Gas Works, Duke Street, Liverpool.

1872. Kirk, Alexander Carnegie, Messrs. Robert Napier and Sons, Lanefield House, Glasgow; and Govan Park, Govan, Glasgow.

1877. Kirk, Henry, Messrs. Kirk Brothers and Co., New Yard Iron Works, Workington. . [*Kirks, Workington.*]

1884. Kirkaldy, John, 40 West India Dock Road, London, E. [*Compactum, London.*]

1875. Kirkwood, James, Chief Inspector of Machinery for Pei Yang Squadron; care of Imperial Maritime Customs, Chefoo, China.

1864. Kirtley, William, Locomotive Superintendent, London Chatham and Dover Railway, Longhedge Works, Wandsworth Road, London, S.W. [3005.]

1859. Kitson, Sir James, Bart., Monk Bridge Iron Works, Leeds.

1868. Kitson, John Hawthorn, Airedale Foundry, Leeds. [*Airedale, Leeds.*]

1874. Klein, Thorvald, Suffolk House, Laurence Pountney Hill, London, E.C.

1886. Knight, Charles Albert, Babcock and Wilcox Boiler Co., 107 Hope Street, Glasgow.

1877. Kortright, Lawrence Moore, Superintendent of Public Works, St. Kitts. West Indies: (or care of G. D. Kortright, Plas Teg, near Mold. Flintshire.)

1881. Laing, Arthur, Deptford Shipbuilding Yard, Sunderland.

1872. Laird, Henry Hyndman, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1872. Laird, William, Messrs. Laird Brothers, Birkenhead Iron Works, Birkenhead.

1883. Lake, William Robert, 45 Southampton Buildings, London, W.C. [*Scopo, London.*]

1878. Lambourn, Thomas William, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich.

1881. Langdon, William, Locomotive Superintendent and Chief Mechanical Engineer, Rio Tinto Railway and Mines, Huelva, Spain: (or care of T. C. Langdon, Tamar Terrace, Launceston.)

1881. Lange, Frederick Montague Townshend, Messrs. Lange's Wool-Combing Works, Saint Acheul-les-Amiens, Somme, France.

1877. Lange, Hermann Ludwig, Manager, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1879. Langley, Alfred Andrew, Engineer-in-Chief, Midland Railway, Derby.

1879. Lapage, Richard Herbert, Bank Chambers, 109 New Oxford Street, London, W.C. [*Lapage, London.*]

1879. Larsen, Jorgen Daniel, 24 Belvedere Road, Upper Norwood, London, S.E.

1881. Lavalley, Alexander, 48 Rue de Provence, Paris.

1867. Lawrence, Henry, The Grange Iron Works, Durham.

1874. Laws, William George, Borough Engineer and Town Surveyor, Town Hall, Newcastle-on-Tyne; and 5 Winchester Terrace, Newcastle-on-Tyne. [*Engineer, Newcastle-on-Tyne.*]

1882. Lawson, Frederick William, Messrs. Samuel Lawson and Sons, Hope Foundry, Leeds.

1870. Layborn, Daniel, Messrs. Caine and Layborn, Dutton Street, Liverpool.

1883. Laycock, William S., Messrs. Samuel Laycock and Sons, Horse-hair Cloth Works, Sheffield; and Ranmoor, Sheffield.

1860. Lea, Henry, Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1884. Leake, Arthur Hill, Sugar Engineer, Post Office, Brisbane, Queensland: (or care of Henry I. Wenham, 43 Finsbury Circus, London, E.C.)

1883. Leavitt, Erasmus Darwin, Jun., 604 Main Street, Cambridgeport, Massachusetts, United States.

1865. Ledger, Joseph, Keswick.

1886. Lee, Charles Eyre, 48 Manor Park Road, Harlesden, London, N.W.

1862. Lee, J. C. Frank, 9 Park Crescent, Portland Place, London, W.

1871. Lee, William, Messrs. Lee Clerk and Robinson, Gospel Oak Iron Works, Tipton; and 110 Cannon Street, London, E.C.

1863. Lees, Samuel, Messrs. H. Lees and Sons, Park Bridge Iron Works, Ashton-under-Lyne.

1883. Lennox, John, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1882. Léon, Auguste, Locomotive Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, 220 Boulevard Voltaire, Paris.

1858. Leslie, Andrew, Coxlodge Hall, Newcastle-on-Tyne.

1883. Leslie, Joseph, Marine Engineer, Messrs. Apcar and Co., Raddah Bazar, Calcutta.

1878. Lewis, Gilbert, Manager, New Bridge Foundry, Adelphi Street, Salford, Manchester.

1884. Lewis, Henry Watkin, Abercanaid, near Merthyr Tydfil.

1872. Lewis, Richard Amelius, Messrs. John Spencer and Sons, Tyne Hæmatite Iron Works, Scotswood-on-Tyne.

1884. Lewis, Sir William Thomas, Bute Mineral Estate Office, Aberdare; and Mardy, Aberdare.

1880. Lightfoot, Thomas Bell, Cornwall Buildings, 35 Queen Victoria Street, London, E.C. [*Separator, London.*]

1856. Linn, Alexander Grainger, 121 Upper Parliament Street, Liverpool.

1876. Lishman, Thomas, Mining Engineer, Hetton Colliery, near Fence Houses.

1881. List, John, Superintendent Engineer, Messrs. Donald Currie and Co., Orchard Works, Blackwall, London, E.

1885. Lister, Frank, Messrs. Wilkinson and Lister, Bradford Road Works, Keighley.

1866. Little, George, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Livesey, James, 2 Victoria Mansions, Victoria Street, Westminster, S.W.

1886. Livsey, John Edward, Demonstrator in Mechanics and Mathematics, Normal School of Science, South Kensington, London, S.W.

1867. Lloyd, Charles, care of Edward J. Lloyd, 289 Norwood Road, Herne Hill, London, S.E.

1871. Lloyd, Francis Henry, James Bridge Steel Works, near Wednesbury [*Steel, Wednesbury*]; and Wood Green, Wednesbury.

1854. Lloyd, George Braithwaite (*Life Member*), Edgbaston Grove, Birmingham.

1882. Lloyd, Robert Samuel, Messrs. Hayward Tyler and Co., 84 Upper Whitecross Street, London, E.C.

1864. Lloyd, Sampson Zachary, Areley Hall, Stourport.

1852. Lloyd, Samuel, The Farm, Sparkbrook, Birmingham.

1879. Lockhart, William Stronach, Fenchurch House, 7 Fenchurch Street, London, E.C.

1881. Lockyer, Norman Joseph, care of A. M. Rendel, 8 Great George Street, Westminster, S.W.

1884. Logan, Andrew Linton, Vulcan Foundry, Newton-le-Willows, Lancashire.

1883. Logan, Robert Patrick Tredennick, Engineer's Office, Great Northern Railway of Ireland, Dundalk.

1874. Logan, William, Mining Engineer, Langley Park Colliery, Durham.

1884. Longbottom, Luke, Locomotive Carriage and Wagon Superintendent, North Staffordshire Railway, Stoke-on-Trent.

1885. Longden, John Needham, Mining Engineer, Messrs. W. Pritchard-Morgan and Co., 1 Queen Victoria Street, London, E.C.

1880. Longridge, Michael, Chief Engineer, Engine and Boiler Insurance Co., 12 King Street, Manchester.

1856. Longridge, Robert Bewick, Managing Director, Engine and Boiler Insurance Co., 12 King Street, Manchester; and Yew Tree House, Tabley, near Knutsford.

1875. Longridge, Robert Charles, Kilrie, Knutsford.

1880. Longworth, Daniel, Carnac Iron Works, Bombay.

1861. Low, George, Bishop's Hill Cottage, Ipswich.
1885. Low, Robert, Laboratory Department, Royal Arsenal, Woolwich.
1884. Lowcock, Arthur, Colcham Foundry, Shrewsbury.
1884. Lowdon, John, Manager, Tyneside Engine Works, Cardiff. [*Tyneside, Cardiff.*]
1873. Lowe, John Edgar, Messrs. Bolling and Lowe, 2 Laurence Pountney Hill, London, E.C. [*Bird, London.* 1530.]
1883. Lowe, Sutton Harvey, Eastgate House, Lincoln.
1873. Lucas, Arthur, 15 George Street, Hanover Square, London, W.
1877. Lupton, Arnold, Professor of Mining Engineering, Yorkshire College, Leeds; and 4 Albion Place, Leeds.
1878. Lynde, James Henry, 32 St. Ann's Street, Manchester.

1883. Macbeth, Norman, Messrs. John and Edward Wood, Victoria Foundry, Bolton.
1884. MacCarthy, Samuel, Messrs. Hathorn Davey and Co., Sun Foundry, Leeds.
1877. MacColl, Hector, Messrs. James Jack and Co., Victoria Engine Works, Boundary Street West, Vauxhall Road, Liverpool.
1879. Macdonald, Augustus Van Zundt, District Manager, New Zealand Railways, Napier, New Zealand.
1885. Mackenzie, John William, Messrs. Wheatley and Mackenzie, 156 Strand, London, W.C.
1884. Mackintosh, Archibald Robert, Post Office, Melbourne, Victoria.
1875. Maclagan, Robert, Chief Engineer, Imperial Mint, Osaka, Japan: (or care of Dr. Maclagan, 9 Cadogan Place, Belgrave Square, London, S.W.)
1886. MacLean, Alexander Scott, Messrs. Alexander Scott and Sons, Sugar Refinery, Berry-yards, Greenock.
1877. MacLellan, John A., Messrs. Alley and MacLellan, Sentinel Works, Polmadie Road, Glasgow. [*Alley, Glasgow.* 673.]
1864. Macnab, Archibald Francis, Inspecting and Examining Engineer, Government Marine Office, Tokio, Japan.
1865. Macnee, Daniel, 2 Westminster Chambers, Victoria Street, Westminster, S.W. [*Macnee, London.*]; and Rotherham.
1884. Macpherson, Alexander Sinclair, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.
1879. Maginnis, James Porter, 9 Carteret Street, Queen Anne's Gate, Westminster, S.W. [*James Maginnis, London.*]
1873. Mair, John George, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W. [*Screwcock, London.*]
1884. Mais, Henry Coathupe, Engineer-in-Chief to the Government of South Australia, Jeffcott Street, North Adelaide, South Australia: (or care of Joseph Meilbck, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1879. Malcolm, Bowman, Locomotive Superintendent, Belfast and Northern Counties Railway, Belfast.

1881. Mallory, George Benjamin, 55 Broadway, New York.

1876. Manlove, William Melland, Messrs. S. Manlove and Sons, Holy Moor Sewing-Cotton Spinning Mills, near Chesterfield.

1862. Mansell, Richard Christopher, Camden House, Barnstaple.

1875. Mansergh, James, 3 Westminster Chambers, Victoria Street, Westminster, S.W.

1862. Mappin, Sir Frederick Thorpe, Bart., M.P., Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield; and Thornbury, Sheffield.

1882. Mappin, Walter Sandell, 13 Cornhill, London, E.C.

1857. March, George, Messrs. Maclea and March, Union Foundry, Dewsbury Road, Leeds. [*Maclea, Leeds.*]

1878. Marié, Georges, Engineer, Chemins de fer de Paris à Lyon et à la Méditerranée, Bureaux du Matériel, Boulevart Mazas, Paris.

1856. Markham, Charles, Staveley Coal and Iron Works, Staveley, near Chesterfield; and Tapton House, Chesterfield.

1884. Marquand, Augustus John, Pierhead Chambers, Cardiff.

1871. Marsh, Henry William, Winterbourne, near Bristol.

1875. Marshall, Alfred (*Life Member*), Perseverance Iron Works, Heneage Street, Whitechapel, London, E.; and Laurel Bank, Prospect Hill, Walthamstow, Essex.

1865. Marshall, Francis Carr, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Marshall, Henry Dickenson, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1871. Marshall, James, Messrs. Marshall Sons and Co., Britannia Iron Works, Gainsborough. [*Marshalls, Gainsborough.* 6648.]

1885. Marshall, Jenner Guest, Westcott Barton Manor, Oxfordshire.

1877. Marshall, William Bayley, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1847. Marshall, William Prime, 15 Augustus Road, Birmingham. [*Augustus, Birmingham.*]

1859. Marten, Edward Bindon, Chief Engineer, Midland Steam Boiler Inspection and Assurance Company, 56 Hagley Street, Stourbridge [*Marten, Stourbridge.*]; Pedmore, Stourbridge; and 4 Storey's Gate, Westminster, S.W.

1853. Marten, Henry John, The Birches, Codsall, near Wolverhampton; and 4 Storey's Gate, Westminster, S.W.

1881. Martin, Edward Pritchard, Dowlais Iron Works, Dowlais.

1878. Martin, Henry, Hanwell, Middlesex, W.

1880. Martin, Robert Frewen, Mount Sorrel Granite Co., Loughborough.

1886. Martin, William Hamilton, Engineering Manager, The Scheldt Royal Shipbuilding and Engineering Works, Flushing, Holland.

1882. Masefield, Robert, Manor Iron Works, Manor Street, Chelsea, London, S.W.

1884. Massey, George, Foy's Chambers, Bond Street, Sydney, New South Wales. [*Masseybond, Sydney.*]

1876. Mather, John, 21 Priory Road, South Lambeth, London, S.W.

1867. Mather, William, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1883. Mather, William Penn, Messrs. Mather and Platt, Salford Iron Works, Manchester. [*Mather, Manchester.*]

1882. Matheson, Henry Cripps, care of Messrs. Russell and Co., Hong Kong, China: (or care of Messrs. Matheson and Grant, 32 Walbrook, London, E.C.)

1875. Matthews, James, 22 Ashfield Terrace East, Newcastle-on-Tyne.

1886. Matthews, Robert, Messrs. Goodfellow and Matthews, Hyde Iron Works, Hyde, near Manchester. [*Goodfellow, Hyde.*]

1875. Mattos, Antonio Gomes de, Messrs. Maylor and Co., Engineering Works, 136 Rua da Sande, Rio de Janeiro, Brazil: (or care of Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.)

1853. Maudslay, Henry (*Life Member*), Westminster Palace Hotel, Victoria Street, Westminster, S.W.: (or care of John Barnard, 47 Lincoln's Inn Fields, London, W.C.)

1869. Maughan, Thomas, Engineer, Cramlington Colliery, Cramlington, Northumberland.

1873. Maw, William Henry, 35 Bedford Street, Strand, London, W.C.

1884. Maxim, Hiram Stevens, 57D Hatton Garden, London, E.C. [*Maxim, London.* 6507.]

1865. Maylor, John, Churton Lodge, Churton, near Chester.

1859. Maylor, William, St. James's, Lordship Lane, London, S.E.

1874. McClean, Frank, Norfolk House, Norfolk Street, Strand, London, W.C.

1872. McConnochie, John, Engineer to the Bute Harbour Trust, 16 Bute Crescent, Bute Docks, Cardiff.

1878. McDonald, John Alexander, Assistant Engineer for Roads and Bridges, Public Works Office, Sydney, New South Wales: (or care of James E. McDonald, 4 Chapel Street, Cripplegate, London, E.C.)

1865. McDonnell, Alexander, Saltwell Hall, Gateshead.

1881. McGregor, Josiah, Crown Buildings, 78 Queen Victoria Street, London, E.C. [*Sahib, London.*]

1868. McKay, Benjamin, Ellerslie, Mackay, Queensland: (or care of Henry C. Halliday, 4 Chestnut Grove, Springfield, Sale, Manchester.)

1881. McKay, John, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1880. McLachlan, John, Messrs. Bow McLachlan and Co., Thistle Engine Works, Paisley. [*Bow, Paisley.*]

1882. McLaren, Raynes Lauder, Bourse Buildings, 20 Bucklersbury, London, E.C.; and 14 Royal Parade, Blackheath, London, S.E. [*Pellmack, London.*]

1879. McLean, William Leckie Ewing, Lancefield Forge Co., Glasgow.

1885. McNeil, John, Messrs. Aitken McNeil and Co., Helen Street, Govan, Glasgow. [*Colonial, Govan.*]

1884. McOnie, William, Jun., Messrs. W. and A. McOnie, Scotland Street Engine Works, Glasgow. [*Maconie, Glasgow.* 565.]

1882. Meats, John Tempest, Mason Machine Works, Taunton, Massachusetts, United States.

1863. Meek, Sturges, Consulting Engineer, Lancashire and Yorkshire Railway, Manchester; and Dunstall Lodge, 18 Holland Villas Road, London, W.

1881. Meik, Charles Scott, 21 York Place, Edinburgh.

1858. Meik, Thomas, 21 York Place, Edinburgh.

1883. Melrose, James, R.N., Bundoraw Villa, Campbell Road, Southsea, B.O., Portsmouth.

1878. Menier, Henri, 56 Rue de Châteaudun, Paris.

1876. Menzies, William, Messrs. Menzies and Blagburn, 9 Dean Street, Newcastle-on-Tyne.

1875. Merryweather, James Compton, Messrs. Merryweather and Sons, Fire-Engine Works, Greenwich Road, London, S.E.; and 63 Long Acre, London, W.C. [*Merryweather, London.*]

1881. Meysey-Thompson, Arthur Herbert, Messrs. Hathorn Davey and Co., Sun Foundry, Dewsbury Road, Leeds.

1877. Michele, Vitale Domenico de, 14 Delahay Street, Westminster, S.W.; and Higham Hall, Rochester.

1884. Middleton, Reginald Empson, 49 Parliament Street, Westminster, S.W.

1886. Midelton, Thomas, Locomotive Overseer, New South Wales Railway, Sydney, New South Wales.

1862. Miers, Francis C., Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and Eden Cottage, West Wickham Road, Beckenham. [*Foundation, London.* 1920.]

1864. Miers, John William, 74 Addison Road, Kensington, London, W.

1874. Milburn, John, Hawkshead Foundry, Quay Side, Workington.

1885. Miller, Harry William, Engineer, Pioneer Powder Factory, Bariaanspoort, Pretoria, South Africa.

1886. Miller, John Smith, Messrs. Smith Brothers and Co., Hyson Green Works, Nottingham.

1885. Millis, Charles Thomas, Technical College, Finsbury, London, E.C.

1856. Mitchell, Charles, Sir W. G. Armstrong Mitchell and Co., Low Walker, Newcastle-on-Tyne; and Jesmond Towers, Newcastle-on-Tyne.

1870. Moberly, Charles Henry, Messrs. Easton and Anderson, Erith Iron Works, Erith, S. O., Kent.

1879. Moffat, Thomas, Mining Engineer, Montreal Iron Ore Mines, Whitehaven.

1885. Moir, James, Superintendent Engineer, Bombay Steam Navigation Co., Frere Road, Bombay.

1879. Molesworth, Guilford Lindsay, Consulting Engineer to the Government of India for State Railways, Supreme Government, India.

1882. Molesworth, James Murray, Cape Copper Co., Ookiep, Namaqualand, Cape Colony; and Spotland Vicarage, Rochdale: (or care of Messrs. Price and Belsham, 52 Queen Victoria Street, London, E.C.)

1881. Molinos, Léon, 48 Rue de Provence, Paris.

1885. Monk, Edwin, care of Josiah McGregor, Crown Buildings, 78 Queen Victoria Street, London, E.C.

1884. Monroe, Robert, Manager, Penarth Slipway and Engineering Works, Penarth Dock, Penarth.

1872. Moon, Richard, Jun., Penyvoel, Llanymynech, Montgomeryshire.

1884. Moore, Benjamin Theophilus, Longwood, Bexley, S. O., Kent.

1876. Moore, Joseph, Risdon Iron and Locomotive Works, San Francisco, California; 6 Durham Road, East End, Finchley, London, N.: (or care of Ralph Moore, Government Inspector of Mines, Rutherglen, Glasgow.)

1882. Moore, Richard St. George, Messrs. Clarke and Moore, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1872. Moorsom, Warren Maude, Linden Lodge, Clevedon.

1880. Moreland, Richard, Jun., Messrs. Richard Moreland and Son, 3 Old Street, St. Luke's, London, E.C. [*Expansion, London.*]

1885. Morgan, Thomas Rees, Morgan Engineering Works, Alliance, Ohio, United States.

1874. Morris, Edmund Legh, New River Water Works, Finsbury Park, London, N.

1885. Morse, Harold, St. Mary's Vicarage, Nottingham.

1858. Mountain, Charles George, Rose Hill House, Coalbrookdale, Shropshire.

1886. Mountain, William Charles, Gülcher Electric-Light and Power Co., Battersea Foundry, London, S.W.

1884. Mower, George A., Crosby Steam Gage and Valve Co., 87 Queen Victoria Street, London, E.C. [*Crosby, London.*]

1885. Mudd, Thomas, Manager, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1873. Muir, Alfred, Messrs. William Muir and Co., Britannia Works, Sherborne Street, Strangeways, Manchester.

1873. Muir, Edwin, 26 King Street, Manchester.

1863. Muir, William, 2 Walbrook, London, E.C.; and 143 Brockley Road, New Cross, London, S.E.

1876. Muirhead, Richard, Messrs. Drake and Muirhead, Maidstone.

1865. Murdock, William Mallabey, Gilwern, near Abergavenny.

1881. Musgrave, James, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1863. Musgrave, John, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1882. Musgrave, Walter Martin, Messrs. John Musgrave and Sons, Globe Iron Works, Bolton. [*Musgrave, Bolton.*]

1870. Napier, James Murdoch, Messrs. David Napier and Son, Vine Street, York Road, Lambeth, London, S.E.

1861. Naylor, John William, Messrs. Fairbairn Naylor Macpherson and Co., Wellington Foundry, Leeds.

1883. Neate, Percy John, Messrs. Taylor and Neate, Medway Works, Rochester.

1863. Neilson, Walter Montgomerie, Hyde Park Locomotive Works, Glasgow; and Queen's Hill, Ringford, Kirkcudbrightshire.

1884. Nelson, John, 39 Botham, York.

1881. Nesfield, Arthur, 7 Rumford Street, Liverpool.

1882. Nettlefold, Hugh, Screw Works, Broad Street, Birmingham. [*Nettlefolds, Birmingham.*]

1879. Neville, Robert, Butleigh Court, Glastonbury.

1879. Newall, Robert Stirling, F.R.S., Wire Rope Works, Gateshead; and Ferndene, Gateshead.

1866. Newdigate, Albert Lewis (*Life Member*), Engineer's Office, Dover Harbour, Dover.

1885. Newlove, Robert Robson, Crown Iron Works, Crocus Street, Nottingham. [*Newlove, Nottingham.*]

1882. Nicholl, Edward McKillop, Bengal Public Works Department, Amritsar, Punjaub, India: (or care of Messrs. Henry S. King and Co., 65 Cornhill, London, E.C.)

1884. Nicholls, James Mayne, East Street, Bridport.

1884. Nicholson, Henry, care of G. H. Hill, Albert Chambers, Albert Square, Manchester.

1884. Nicholson, Thomas Head, 32 Rye Hill, Newcastle-on-Tyne.

1884. Nicholson, Walter Elliott, Oakfield, Ryton-on-Tyne, R. S. O., County Durham.

1877. Nicolson, Donald, 42 Highbury Hill, London, N.

1886. Noakes, Thomas Joseph, Messrs. Thomas Noakes and Sons, 35 and 37 Brick Lane, Whitechapel, London, E.

1884. Noakes, Walter Maplesden, 43 York Street, Wynyard Square, Sydney, New South Wales.

1882. Nordenfelt, Thorsten, 53 Parliament Street, Westminster, S.W.

1868. Norris, William Gregory, Coalbrookdale Iron Works, Coalbrookdale, Shropshire.

1869. North, Frederic William, Mining Engineer, Rowley Hall, near Dudley.

1883. North, Gamble, Messrs. North and Jewel, Peruano Nitrate of Soda and Iodine Works, Iquique, Chile: (or care of John T. North, Avery House, Avery Hill, Eltham.)

1882. North, John Thomas, Messrs. North Humphrey and Dickenson, Engineering Works, Iquique, Chile; and Avery House, Avery Hill, Eltham.

1878. Northcott, William Henry, General Engine and Boiler Co., Hatcham Iron Works, Pomeroy Street, New Cross Road, London, S.E.; and 7 St. Mary's Road, Peckham, London, S.E. [*Oxygen, London.* 8007.]

1882. Nunneley, Thomas, 9 Beech Grove Terrace, Leeds.

1885. Oakes, Sir Reginald Louis, Bart., York Engineering Works, Leeman Road, York.

1868. O'Connor, Charles, Mersey Forge, Liverpool.

1886. Ogle, Percy John, 4 Bishopsgate Street Within, London, E.C.

1875. Okes, John Charles Raymond, 39 Queen Victoria Street, London, E.C. [*Oaktree, London.* 1601.]

1866. Oliver, William, Cobden Road, Chesterfield.

1882. Olrick, Harry, 27 Leadenhall Street, London, E.C.

1882. Orange, James, Surveyor General's Department, Hong Kong, China: (or care of Mrs. Mary Orange, 2 West End Terrace, Jersey.)

1885. Ormerod, Richard Oliver, 35 Philbeach Gardens, South Kensington, London, S.W.

1870. Osborn, Samuel, Clyde Steel and Iron Works, Sheffield. [*Osborn, Sheffield.*]

1867. Oughterson, George Blake, care of Peter Brotherhood, Belvedere Road, Lambeth, London, S.E.

1886. Owen, Thomas Henry, Dumfries Dry Dock Co., Pier Head, Cardiff.

1868. Paget, Arthur, Machine Works, Loughborough.

1881. Palmer, Cecil Brooke, Minnie Moor Mining Co., Bellevue, Idaho, United States.

1877. Panton, William Henry, General Manager, Stockton Forge, Stockton-on-Tees. [*Forge, Stockton-on-Tees.*]

1877. Park, John Carter, Locomotive Engineer, North London Railway, Bow, London, E.

1871. Parke, Frederick, Withnell Fire Clay Works, near Chorley.

1872. Parker, Thomas, Locomotive Carriage and Wagon Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, near Manchester.

1879. Parker, William, Chief Engineer Surveyor, Lloyd's Register, 2 White Lion Court, Cornhill, London, E.C.

1871. Parkes, Persehouse, care of Messrs. Henry Persehouse Parkes and Co., 7 Gorce Piazzas, Liverpool. [*Persehouse, Liverpool.*]

1884. Parlane, William, Hong Kong Ice Works, Eastpoint, Hong Kong, China.

1886. Parry, Alfred, Messrs. Balmer Lawrie and Co., 103 Clive Street, Calcutta, India.

1880. Parsons, The Hon. Charles Algernon, Elvaston Hall, Ryton-on-Tyne, R.S.O., County Durham.

1878. Parsons, The Hon. Richard Clere, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1886. Passmore, Frank Bailey, Elmhurst, Hamstead Road, Handsworth, R.O., Birmingham.

1880. Paterson, Walter Saunders, Bombay Burmah Trading Corporation, Rangoon, British Burmah, India : (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1877. Paton, John McClure Caldwell, Messrs. Manlove Alliott Fryer and Co., Bloomsgrove Works, Ilkeston Road, Nottingham. [*Manloves, Nottingham.*]

1881. Patterson, Anthony, Dowlais Iron Works, Dowlais.

1881. Pattinson, John, 15 Princes Street, Yeovil.

1883. Pattison, Giovanni, Messrs. C. and T. T. Pattison, Engineering Works, Naples. [*Pattison, Naples.*]

1884. Paul, Andrew Louis, Engineer, Oriental Telephone Co., India; (care of Messrs. Benn Ashley and Co., Bombay, India) ; and 38 Ashburn Place, London, S.W.

1872. Paxman, James Noah, Messrs. Davey Paxman and Co., Standard Iron Works, Colchester. [*Paxman, Colchester.*]

1880. Peache, James Courthope, Messrs. Willans and Robinson, Ferry Works, Thames Ditton.

1869. Peacock, Ralph, Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester.

1869. Peacock, Ralph, Aire and Calder Foundry, Goole.

1847. Peacock, Richard, M.P., Messrs. Beyer Peacock and Co., Gorton Foundry, Manchester ; and Gorton Hall, Gorton, near Manchester.

1879. Pearce, George Cope, Ryefields, Ross.

1873. Pearce, Richard, Deputy Carriage and Wagon Superintendent, East Indian Railway, Howrah, Bengal, India: (or care of W. J. Titley, 57 Lincoln's Inn Fields, London, W.C.)

1867. Pearce, Robert Webb, Carriage Superintendent, East Indian Railway, Howrah, Bengal, India; and 47 Gunterstone Road, West Kensington, London, W.

1884. Pearson, Frank Henry, Earle's Shipbuilding and Engineering Works, Hull.

1885. Pearson, Henry William, Engineer, Bristol Water Works, Small Street, Bristol.

1870. Pearson, Thomas Henry, Moss Side Iron Works, Ince, near Wigan.

1883. Peck, Walter, Greymouth, Nelson, New Zealand: (or care of J. H. Peck, 52 Hoghton Street, Southport.)

1884. Penn, George Williams, Lloyd's Bute Proving House, Cardiff.

1873. Penn, John, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1873. Penn, William, Messrs. John Penn and Sons, Marine Engineers, Greenwich, S.E.

1874. Pepper, Joseph Ellershaw, Clarence Iron Works, Leeds.

1874. Percy, Cornelius McLeod, King Street, Wigan.

1861. Perkins, Loftus, Messrs. A. M. Perkins and Son, 6 Seaford Street, Regent Square, London, W.C.

1879. Perkins, Stanhope, Assistant Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Gorton, Manchester.

1882. Perry, Alfred, Lighthouse Department, Messrs. Chance Brothers and Co., Spon Lane, near Birmingham.

1865. Perry, William, Claremont Place, Wednesbury.

1882. Petherick, Vernon, Post Office, Brisbane, Queensland: (or care of Messrs. Manlove Alliott Fryer and Co., Ilkeston Road, Nottingham.)

1881. Philipson, John, Messrs. Atkinson and Philipson, Carriage Manufactory, 15 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]

1885. Phillips, Charles David, Emlyn Engineering Works, Newport, Monmouthshire. [*Machinery, Newport, Mon.*]

1885. Phillips, Henry Parnham, Assistant Locomotive Superintendent, Burma State Railway, Insein, British Burma.

1878. Phillips, John, Manager, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 84 Blackfriars Road, London, S.E.

1885. Phillips, Lionel, Mining Engineer, Bultfontein Diamond Mine, South Africa.

1879. Phillips, Robert Edward, Royal Courts Chambers, 70 and 72 Chancery Lane, London, W.C.; and Rochelle, Selhurst Road, South Norwood, London, S.E. [*Phicycle, London.*]

1882. Phipps, Christopher Edward, Deputy Locomotive Superintendent, Madras Railway, Perambore Works, Madras.

1876. Piercy, Henry James Taylor, Messrs. Piercy and Co., Broad Street Engine Works, Birmingham. [381.]

1877. Pigot, Thomas Francis, Professor of Engineering, Royal College of Science for Ireland, Dublin.

1883. Pillow, Edward, London and North Western Railway, Locomotive Department, Crewe.

1876. Pinel, Charles Louis, Messrs. Lethuillier and Pinel, 26 Rue Meridienne, Rouen, France. [*Lethuillier Pinel, Rouen.*]

1882. Pirrie, John Sinclair, 59 Elgin Road, Addiscombe, Croydon.

1883. Pitt, Walter, Messrs. Stothert and Pitt, Newark Foundry, Bath. [*Stothert, Bath.*]

1871. Platt, James, Messrs. Fielding and Platt, Atlas Iron Works, Gloucester. [*Atlas, Gloucester.*]

1883. Platt, James Edward, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1867. Platt, Samuel Radcliffe, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1878. Platts, John Joseph, Resident Engineer, Odessa Water Works, Odessa, Russia.

1869. Player, John, Clydach Foundry, near Swansea.

1884. Poillon, Louis Marie Joseph, 74 Boulevard Mont-Parnasse, Paris.

1886. Pollock, James, Fenchurch House, 5 and 7 Fenchurch Street, London, E.C. [*Specific, London.*]

1876. Pollock, Julius Frederick Moore, Messrs. Pollock and Pollock, Longelose Works, Newtown, Leeds.

1876. Pooley, Henry, Messrs. Henry Pooley and Son, Albion Foundry, Liverpool. [*Pooley, Liverpool.*]

1864. Potts, Benjamin Langford Foster, 55 Chancery Lane, London, W.C.; and 5 Camden Row, Camberwell, London, S.E.

1878. Powell, Henry Coke, care of Thomas Powell, 23 Rue St. Julien, Rouen, France: (or care of C. M. Roffe, 1 Bedford Row, London, W.C.)

1870. Powell, Thomas (Son), Messrs. Thomas and T. Powell, 23 Rue St. Julien, Rouen, France.

1874. Powell, Thomas (Nephew), Brynhyfryd, Neath.

1867. Pratchitt, John, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1865. Pratchitt, William, Messrs. Pratchitt Brothers, Denton Iron Works, Carlisle.

1885. Pratten, William John, Messrs. Harland and Wolff, Belfast.

1882. Presser, Ernest Charles Antoine, 4 Salesas, Madrid.
1884. Prest, Stanley Faber, Messrs. Westray Copeland and Co., Barrow-in-Furness.
1856. Preston, Francis, Netherfield House, Kirkburton, near Huddersfield. [*Preston, Kirkburton.*]
1877. Price, Henry Sherley, Messrs. Wheatley Kirk, Price, and Goulty, 52 Queen Victoria Street, London, E.C. [*Indices, London.* 1533.]
1866. Price, John, General Manager, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow; and 6 Osborne Villas, Jesmond, Newcastle-on-Tyne.
1859. Price-Williams, Richard, 38 Parliament Street, Westminster, S.W.
1874. Prosser, William Henry, Messrs. Harfield and Co., Blaydon-on-Tyne.
1875. Provis, George Stanton, Ingoldsby, Belvedere Road, Upper Norwood, London, S.E.
1885. Pudan, Oliver, 15 Princes Street, Yeovil.
1884. Puplett, Samuel, 59 Colmore Row, Birmingham. [*Iee, Birmingham.*]
1866. Putnam, William, Darlington Forge, Darlington.

1878. Quillacq, Augustus de, Société anonyme de Constructions mécaniques d'Anzin, Anzin (Nord), France.

1873. Radcliffe, Arthur Henry Wright, 5 Carr's Lane, Birmingham.
1870. Radcliffe, William, Camden House, 25 Collegiate Crescent, Sheffield.
1878. Radford, Richard Heber, 15 St. James' Row, Sheffield.
1868. Rafarel, Frederic William, Cwmbran Nut and Bolt Works, near Newport, Monmouthshire.
1884. Rafarel, William Claude, Barnstaple Foundry and Engineering Works, Victoria Road, Barnstaple. [*Rafarel, Barnstaple.*]
1885. Rainforth, William, Jun., Britannia Iron Works, Lincoln. [*Rainforths, Lincoln.*]
1878. Rait, Henry Milnes, Messrs. Rait and Gardiner, 155 Fenchurch Street, London, E.C.
1847. Ramsbottom, John, Fernhill, Alderley Edge, Cheshire.
1866. Ramsden, Sir James, Abbot's Wood, Barrow-in-Furness.
1860. Ransome, Allen, 304 King's Road, Chelsea, London, S.W. [*Ransome, London.*]
1886. Ransome, James Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]
1869. Ransome, Robert Charles, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich. [*Ransomes, Ipswich.*]
1862. Ransome, Robert James, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich. [*Waterside, Ipswich.*]
1873. Rapier, Richard Christopher, Messrs. Ransomes and Rapier, Waterside Iron Works, Ipswich; and 5 Westminster Chambers, Victoria Street, Westminster, S.W. [*Ransomes, Westminster.*]

1883. Rathbone, Edgar Philip, Mining Engineer, 2 Great George Street, Westminster, S.W. [*Basera, London.* 3117.]

1867. Ratliffe, George, 81 Cannon Street Buildings, 139 Cannon Street, London, E.C.

1862. Ravenhill, John R., River Thames Steamboat Company, Adelaide Buildings, London Bridge, London, E.C.; and 27 Courtfield Gardens, South Kensington, London, S.W. [2230.]

1872. Rawlins, John, Manager, Metropolitan Railway-Carriage and Wagon Works, Saltley, Birmingham. [*Metro, Birmingham.*]

1878. Rawlinson, Sir Robert, C.B., Chief Inspector, Local Government Board, Whitehall, London, S.W.

1883. Reader, Reuben, Phœnix Works, Cremorne Street, Nottingham.

1882. Reay, Thomas Purvis, Messrs. Kitson and Co., Airedale Foundry, Leeds.

1881. Redpath, Francis Robert, Canada Sugar Refinery, Montreal, Canada. [*Redpath, Montreal.*]

1883. Reed, Alexander Henry, 90 Cannon Street, London, E.C. [*Wagon, London.*]

1881. Reed, Charles Holloway, Trimdon Iron Works, Sunderland. [*Chreed, Sunderland.* 17.]

1870. Reed, Sir Edward James, K.C.B., M.P., F.R.S., Broadway Chambers, Westminster, S.W. [*Carnage, London.*]

1884. Rees, William David, Swansea Railway-Carriage and Wagon Works, Swansea.

1884. Rees, William Thomas, Mining Engineer, Gadlys Cottage, Aberdare.

1883. Reid, James, Messrs. Neilson and Co., Hyde Park Locomotive Works, Glasgow.

1859. Rennie, George Banks, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.; and 20 Lowndes Street, Lowndes Square, London, S.W.

1879. Rennie, John Keith, Messrs. J. and G. Rennie, Albion Iron Works, Holland Street, Blackfriars Road, London, S.E.

1881. Rennoldson, Joseph Middleton, Marine Engine Works, South Shields. [*Rennoldson, South Shields.* 11.]

1876. Restler, James William, Engineer, Southwark and Vauxhall Water Works, Sumner Street, Southwark, London, S.E.

1883. Reunert, Theodore, Kimberley, South Africa; and Benson's Buildings, Park Row, Leeds.

1862. Reynolds, Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1879. Reynolds, George Bernard, Assistant Manager, Wardha Coal State Railway, Warora, Central Provinces, India.

1882. Rhodes, Vincent, Manager, Messrs. Hudson Brothers, Clyde Engineering Works, Granville, near Sydney, New South Wales: (or care of Mrs. E. A. Rhodes, 5 Ainger Terrace, St. Catherine's Road, Grantham.)

1875. Rich, William Edmund, 104 St. George's Square, London, S.W.

1866. Richards, Edward Windsor, Messrs. Bolckow Vaughan and Co., Iron Works, Middlesbrough.

1882. Richards, George, Messrs. George Richards and Co., Atlantic Works, Broadheath, near Manchester. [*Richards, Altrincham.*]

1856. Richards, Josiah, Pontypool Iron and Tinplate Works, Pontypool.

1884. Richards, Lewis, Dowlais Iron and Steel Works, Dowlais.

1863. Richardson, The Hon. Edward, C.M.G., Minister of Public Works, Christchurch, Canterbury, New Zealand.

1865. Richardson, John, Methley Park, near Leeds.

1873. Richardson, John, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1859. Richardson, William, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham.

1884. Riches, Charles Hurry, Assistant Locomotive Superintendent, Taff Vale Railway, Cardiff.

1874. Riches, Tom Hurry, Locomotive Superintendent, Taff Vale Railway, Cardiff. [*Locomotive, Cardiff.*]

1873. Rickaby, Alfred Austin, Bloomfield Engine Works, Sunderland. [*Rickaby, Sunderland.*]

1879. Ridley, James Cartmell, Queen Street, Newcastle-on-Tyne.

1863. Rigby, Samuel, Fern Bank, Liverpool Road, Chester.

1874. Riley, James, General Manager, Steel Company of Scotland, 150 Hope Street, Glasgow.

1884. Ripper, William, Assistant Professor of Mechanical Engineering, The Technical School, St. George's Square, Sheffield.

1879. Rixom, Alfred John, 38 The Grove, Hammersmith, London, W.

1879. Roberts, Thomas Herbert, Mechanical Superintendent, Chicago and Grand Trunk Railway, Detroit, Michigan, United States.

1848. Robertson, Henry, Great Western Railway, Shrewsbury; 13 Lancaster Gate, London, W.; and Palé, Corwen.

1879. Robertson, William, Messrs. Boyd and Co., Engineers and Shipbuilders, Shanghai, China: (or care of Herbert J. Stockton, 16 Philpot Lane, London, E.C.)

1883. Robins, Edward, Assistant Engineer, Public Works Department, 62 Brickdam, George Town, Demerara, British Guiana: (or care of Charles Robins, 3 Holmdale Road, Denington Park, West Hampstead, London, N.W.)

1874. Robinson, Henry, 7 Westminster Chambers, Victoria Street, Westminster, S.W.

1876. Robinson, James Salkeld, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1859. Robinson, John, Messrs. Sharp Stewart and Co., Atlas Works, Manchester; and Westwood Hall, Leek, near Stoke-upon-Trent.

1886. Robinson, John, Barry Dock and Railways, Barry, near Cardiff.

1878. Robinson, John Frederick, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1878. Robinson, Thomas Neild, Messrs. Thomas Robinson and Son, Railway Works, Rochdale. [*Robinson, Rochdale.*]

1866. Robson, Thomas, Mining Engineer, Lumley Thicks, Fence Houses.

1879. Rodger, William, care of Messrs. Ralli Brothers, Bombay: (or care of Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow.)

1884. Rodrigues, José Maria de Chermont, Rua de S. Pedro 54 sobrado, Rio de Janeiro, Brazil: (or care of Messrs. Jacob Walter and Co., 34 Leadenhall Street, London, E.C.)

1872. Rofe, Henry, Cavendish Hill, Sherwood, Nottingham.

1885. Rogers, Henry John, Watford Iron Works, Watford. [*Engineer, Watford.*]

1871. Rollo, David, Messrs. David Rollo and Sons, Fulton Engine Works, 10 Fulton Street, Liverpool.

1874. Ross, John Alexander George, 46 Grainger Street West, Newcastle-on-Tyne.

1881. Ross, William, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1856. Rouse, Frederick, Great Northern Railway, Locomotive Department, Peterborough.

1878. Routh, William Pole, 25 Rua de S. Francisco, Oporto, Portugal: (or care of Cyril E. Routh, St. Michael's House, Cornhill, London, E.C.)

1880. Routledge, Thomas, Ford Paper Works, Sunderland; and Claxheugh, Sunderland.

1878. Russell, The Hon. William, George Town, Demerara, British Guiana; and 65 Holland Park, London, W.

1867. Ruston, Joseph, Messrs. Ruston Proctor and Co., Sheaf Iron Works, Lincoln; and 6 Onslow Gardens, South Kensington, London, S.W. [*Ruston, Lincoln.*]

1884. Rutherford, George, Manager, Wallsend Slipway and Engineering Works, Cardiff. [*Wall, Cardiff.*]

1877. Rutter, Edward, The Cedars, Richmond, Surrey.

1885. Ryan, John, D.Sc., Professor of Physics and Engineering, University College, Bristol.

1883. Ryder, George, Turner Bridge Iron Works, Tong, near Bolton. [*Ryder, Bolton.* 33A.]

1866. Ryland, Frederick, Messrs. A. Kenrick and Sons, Spon Lane, Westbromwich.

1866. Sacré, Alfred Louis, 60 Queen Victoria Street, London, E.C. [*Sextant, London.* 1668.]

1859. Sacré, Charles, Locomotive Superintendent, Manchester Sheffield and Lincolnshire Railway, Manchester; and Sunnyside, Victoria Park, Manchester.

1883. Sadoine, Baron Eugène, Société Cockerill, Seraing, Belgium.

1864. Said, Colonel M., Pasha, Engineer, Turkish Service, Constantinople: (or care of J. C. Frank Lee, 9 Park Crescent, Portland Place, London, W.)

1859. Salt, George, Sir Titus Salt, Bart., Sons and Co., Saltaire, near Bradford; and Royal Thames Yacht Club, 7 Albemarle Street, London, W.

1874. Sampson, James Lyons, Messrs. David Hart and Co., North London Iron Works, Wenlock Road, City Road, London, N. [*Bascule, London.* 6699.]

1865. Samuelson, Sir Bernhard, Bart., M.P., F.R.S., Britannia Iron Works, Banbury; and 56 Prince's Gate, South Kensington, London, S.W.; and Lupton, Brixham, South Devon.

1881. Samuelson, Ernest, Messrs. Samuelson and Co., Britannia Iron Works, Banbury.

1881. Sanders, Henry Conrad, Messrs. H. G. Sanders and Son, Victoria Works, Victoria Gardens, Notting Hill Gate, London, W.; and 7 Boscombe Road, Shepherd's Bush, London, W.

1871. Sanders, Richard David, Kittsbury House, Berkhamsted.

1886. Sandford, Horatio, Messrs. E. A. and H. Sandford, Thames Iron Works, Gravesend.

1881. Sandiford, Charles, Locomotive and Carriage Superintendent, North Western Railway, Lahore, Punjaub, India.

1874. Sauvée, Albert, 22 Parliament Street, Westminster, S.W. [*Sovez, London.* 3133.]

1882. Sawyer, Frederic Henry Read, 18 Calle Real de San Miguel, Manila, Philippine Islands; and 56 Gresham Road, Brixton, London, S.W.

1880. Saxby, John, Messrs. Saxby and Farmer, Railway Signal Works, Canterbury Road, Kilburn, London, N.W. [*Signalmen, London.*]

1869. Scarlett, James, Messrs. E. Green and Son, 14 St. Ann's Square, Manchester.

1886. Scholes, William Henry, Water Works Engineer, Oficina de Aguas Corrientes, Calle Alsina, Buenos Aires, Argentine Republic: (or care of George Scholes, Orwell House, Upton Manor, Plaistow, London, E.)

1883. Schönheyder, William, 81 St. Stephen's Avenue, Shepherd's Bush, London, W.

1880. Schram, Richard, 9 Northumberland Street, Strand, London, W.C. [*Schram, London.*]

1886. Schurr, Albert Ebenezer, Messrs. Fry Miers and Co., Suffolk House, 5 Laurence Pountney Hill, London, E.C.; and 3 Trafalgar Road, Twickenham.

1885. Scorgie, James, Professor of Applied Mechanics, Civil Engineering College, Poona, India: (or care of Messrs. W. Watson and Co., 27 Leadenhall Street, London, E.C.).

1876. Scott, David, Port Commissioners' Office, Calcutta.

1875. Scott, Frederick Whitaker, Atlas Steel and Iron Wire Rope Works, Reddish, Stockport. [*Atlas, Reddish.*]

1881. Scott, George Innes, 4 Queen Street, Newcastle-on-Tyne.

1877. Scott, Irving M., Messrs. Prescott Scott and Co., Union Iron Works, San Francisco, California.

1881. Scott, James, care of Messrs. Steel Murray and Co., Merchants, Durban, Natal: (or care of Mr. Wallace, The Home Farm, Murthly, Perthshire.)

1886. Scott, James, Consett Iron Works, Consett, R.S.O., County Durham.

1884. Scott, John, Messrs. Charles Hill and Sons, Bristol.

1885. Scott, Robert, Engineer, Messrs. Takata and Co., Tsukiji, Tokio, Japan: (or care of Messrs. H. Ahrens and Co., 17 and 18 Basinghall Street, London, E.C.)

1861. Scott, Walter Henry, Locomotive Superintendent, Great Southern Railway, Buenos Aires, Argentine Republic: (or care of H. Eaton, 75 Tulse Hill, London, S.W.)

1884. Scott-Moncrieff, William Dundas, 4D Upper Baker Street, London, N.W.

1868. Scriven, Charles, Whinfield Mount, Chapel Allerton, Leeds. [*Scriven, Leeds.*]

1882. Seabrook, Alfred William, Engineer Surveyor to the Port of Bombay, Port Office, Bombay.

1882. Seaton, Albert Edward, Earle's Shipbuilding and Engineering Works, Hull.

1864. Seddon, John, 98 Wallgate, Wigan.

1886. Seddon, Robert Barlow, Manager, Wigan Wagon Works, Wigan.

1882. Selfe, Norman, 141 Pitt Street, Sydney, New South Wales.

1884. Sellers, Coleman, Messrs. William Sellers and Co., 1600 Hamilton Street, Philadelphia; and 3301 Baring Street, Philadelphia, Pennsylvania, United States.

1865. Sellers, William, Pennsylvania Avenue, Philadelphia, Pennsylvania, United States.

1881. Sennett, Richard, Admiralty, Whitehall, London, S.W.

1883. Shackleford, Arthur Lewis, General Manager, Britannia Railway-Carriage and Wagon Works, Saltley, Birmingham.

1884. Shackleford, William Copley, Manager, Lancaster Wagon Works, Lancaster.

1872. Shanks, Arthur, Messrs. A. Burn and Co., Howrah Iron Works, Howrah; and 7 Hastings Street, Calcutta: (or care of Messrs. J. Lennox and Co., 2 Victoria Mansions, Victoria Street, Westminster, S.W.)

1884. Shanks, William, Messrs. Thomas Shanks and Co., Johnstone, near Glasgow. [*Shanks, Johnstone.*]

1881. Shanks, William Weallens, 18 Strand Road, Howrah, Bengal.

1881. Shapton, William, Sir William G. Armstrong Mitchell and Co., 8 Great George Street, Westminster, S.W.

1863. Sharp, Henry, Bolton Iron and Steel Works, Bolton.

1875. Sharp, Thomas Budworth, Managing Engineer, Muntz Metal Works, Birmingham.

1869. Sharrock, Samuel, Windsor Iron Works, Garston, near Liverpool; and 8 Old Jewry, London, E.C.

1882. Sharrock, Samuel Lord, Hydraulic Engineering Works, Chester.

1879. Shaw, Henry Selby Hele, Professor of Engineering, University College, Liverpool.

1881. Shaw, Joshua, Messrs. John Shaw and Sons, Wellington Street Works, Salford, Manchester.

1881. Shaw, William, Stanners Closes Steel Works, Wolsingham, near Darlington.

1856. Shelley, Charles Percy Bysshe, 45 Parliament Street, Westminster, S.W.

1861. Shepherd, John, Union Foundry, Hunslet Road, Leeds.

1875. Sheppard, Herbert Gurney, East Indian Railway, Cawnpore, India; and 89 Westbourne Terrace, Hyde Park, London, W.

1876. Shield, Henry, Messrs. Faweett Preston and Co., Phœnix Foundry, 17 York Street, Liverpool.

1885. Shuttleworth, Alfred, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln. [*Claytons, Lincoln.*]

1885. Shuttleworth, Major Frank, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and Old Warden Park, Biggleswade. [*Claytons, Lincoln.*]

1871. Simon, Henry, 20 Mount Street, Manchester. [*Henry Simon, Manchester.*]

1877. Simonds, William Turner (*Life Member*), Messrs. J. C. Simonds and Son, Oil Mills, Boston.

1876. Simpson, Arthur Telford, Engineer, Chelsea Water Works, 38 Parliament Street, Westminster, S.W.

1878. Simpson, James, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1885. Simpson, James Thomas, Executive Engineer, Public Works Department, Chittagong, Bengal.

1882. Simpson, John Harwood, Severn Tunnel Works, Portskewett, near Chepstow.

1847. Sinclair, Robert, care of Messrs. Sinclair Hamilton and Co., 17 St. Helen's Place, Bishopsgate Street, London, E.C. [*Sinclair, London.*]

1857. Sinclair, Robert Cooper, 3 Adelaide Place, London Bridge, London, E.C.

1881. Sisson, William, Messrs. Cox and Co., Falmouth Docks Engine and Shipbuilding Works, Falmouth. [*Sisson, Falmouth.*]

1885. Sivewright, George William, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool.

1872. Slater, Alfred, Gloucester Wagon Works, Gloucester.

1853. Slaughter, Edward, 7 Victoria Square, Clifton, Bristol; and Lyndhurst, Watford.

1885. Slight, William Hooper, Alkmonton Vicarage, Derby.

1886. Small, James Miln, 47 Woburn Place, Russell Square, London, W.C.

1879. Smith, Allison Dalrymple, Locomotive Superintendent, Canterbury Railways, Christchurch, New Zealand.

1879. Smith, Charles Hubert, Engineer and Shipwright Surveyor to the Board of Trade, North Shields.

1866. Smith, Edward Fisher, 34 Avenue Road, Regent's Park, London, N.W.

1866. Smith, George Fereday, Grovehurst, Tunbridge Wells. [*Grovehurst, Pembury, Kent.*]

1860. Smith, Henry, Messrs. Hill and Smith, Brierley Hill Iron Works, Brierley Hill; and Summerhill, Kingswinford, near Dudley. [*Fencing, Brierley Hill.*]

1881. Smith, Henry, Messrs. Simpson and Co., 101 Grosvenor Road, Pimlico, London, S.W.

1860. Smith, John, Parkfield, Duffield Road, Derby.

1876. Smith, John, Wintoun Terrace, Rochdale.

1883. Smith, John Bagnold, Newstead Colliery, near Nottingham.

1857. Smith, Josiah Timmis, Hæmatite Iron and Steel Works, Barrow-in-Furness; and Croslands, Dalton-in-Furness, R.S.O., Lancashire.

1870. Smith, Michael Holroyd, Royal Insurance Buildings, Crossley Street, Halifax.

1886. Smith, Reginald Arthur, 24 Brazenose Street, Manchester.

1881. Smith, Robert Henry, Professor of Engineering, Mason Science College, Birmingham; and 10 St. Augustine's Road, Edgbaston, Birmingham.

1885. Smith, Thomas, Steam Crane Works, Old Foundry, Rodley, near Leeds. [*Tomsmith, Leeds.*]

1881. Smith, Wasteneys, 59 Sandhill, Newcastle-on-Tyne. [*Wasteneys Smith, Newcastle-on-Tyne.* 429.]

1863. Smith, William Ford, Messrs. Smith and Coventry, Gresley Iron Works, Ordsal Lane, Salford, Manchester.

1882. Smyth, James Josiah, Messrs. James Smyth and Sons, Peasenhall, Suffolk.

1884. Smyth, William Stopford, Engineer, Alexandra Docks, Newport, Monmouthshire.

1883. Snelus, George James, West Cumberland Iron and Steel Works, Workington.

1885. Snowball, Edward, Manager, New Plymouth Sash and Door Factory and Timber Co., Gill Street, New Plymouth, Taranaki, New Zealand.

1886. Snowdon, Frederick Seaton, 29 Tasman Road, Clapham, London, S.W.

1885. Snowdon, John Armstrong, Stanners Closes Steel Works, Wolsingham, near Darlington.

1859. Sokoloff, Major-General Alexander, Engineer, Russian Imperial Service, Steam Marine Department, Cronstadt, Russia: (or care of Messrs. W. Collier and Co., Worsley Street, New Bailey Street, Salford, Manchester.)

1878. Sopwith, Thomas, Mining Engineer, 6 Great George Street, Westminster, S.W. [*Sopwith, London.* 3175.]

1884. Soulsby, James Charlton, 17 Mount Stuart Square, Cardiff.

1885. Southwell, Frederick Charles, Messrs. Richard Hornsby and Sons, Spittlegate Iron Works, Grantham.

1877. Soyres, Francis Johnstone de, Messrs. Bush and De Soyres, Bristol Iron Foundry, Bristol.

1878. Spencer, Alfred G., Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1866. Spencer, Eli, Messrs. Platt Brothers and Co., Hartford Iron Works, Oldham; and The Knoll, Fulshaw Park, Wilmslow, near Manchester.

1878. Spencer, George, Messrs. George Spencer and Co., 77 Cannon Street, London, E.C.

1877. Spencer, John, Globe Tube Works, Wednesbury [*Tubes, Wednesbury.*]; and 3 Queen Street Place, Cannon Street, London, E.C. [*Tubes, London.*]

1867. Spencer, John W., Newburn Steel Works, Newcastle-on-Tyne. [*Newburn, Newcastle-on-Tyne.*]

1885. Spencer, Mountford, Messrs. Luke and Spencer, Ardwick, Manchester.

1854. Spencer, Thomas, Newburn Steel Works, Newcastle-on-Tyne. [*Newburn Newcastle-on-Tyne.*]

1876. Spice, Robert Paulson, 21 Parliament Street, Westminster, S.W.

1885. Spooner, George Percival, Locomotive Superintendent, Bolan Railway, Hirok, Beluchistan, India.

1883. Spooner, Henry John, 309 Regent Street, London, W.

1862. Stableford, William, Broadwell House, Oldbury, near Birmingham.

1869. Stabler, James, 13 Effra Road, Brixton, London, S.W.

1880. Stafford, George, 17 Russell Street, Nottingham.

1877. Stanger, George Hurst, Queen's Chambers, North Street, Wolverhampton.

1875. Stanger, William Harry, 23 Queen Anne's Gate, Westminster, S.W.

1884. Stanton, Frederic Barry, Mansion House Chambers, 11 Queen Victoria Street, London, E.C.

1866. Stephens, John Classon, Messrs. Stephens and Co., Vulcan Iron Works, Sir John Rogerson's Quay, Dublin.

1874. Stephens, Michael, Locomotive Superintendent, Cape Government Railways, Cape Town, Cape of Good Hope.

1868. Stephenson, George Robert, 9 Victoria Chambers, Victoria Street, Westminster, S.W. [*Precursor, London.*]

1879. Stephenson, Joseph Gurdon Leycester, 6 Drapers' Gardens, Throgmorton Street, London, E.C.

1876. Sterne, Louis, Messrs. L. Sterne and Co., Crown Iron Works, Glasgow [*Crown, Glasgow.*] ; and 2 Victoria Mansions, Victoria Street, Westminster, S.W. [*Elsterne, London.* 3066.]

1875. Stevens, Arthur James, Uskside Iron Works, Newport, Monmouthshire.

1878. Stevenson, George Wilson, 38 Parliament Street, Westminster, S.W.

1877. Stewart, Alexander, Manager, Messrs. Thwaites Brothers, Vulcan Iron Works, Thornton Road, Bradford.

1878. Stewart, Duncan, Messrs. Duncan Stewart and Co., London Road Iron Works, Glasgow. [*Stewart, Glasgow.* 531.]

1851. Stewart, John, Blackwall Iron Works, Poplar, London, E. [*Steamships, London.*]

1885. Stewart-Hamilton, Patrick, care of Rev. Alexander Hamilton, D.D., The Manse, Brighton.

1880. Stirling, James, Locomotive Superintendent, South Eastern Railway, Ashford, Kent.

1885. Stirling, Matthew, Locomotive Superintendent, Hull Barnsley and West Riding Junction Railway and Dock Co., Hull.

1867. Stirling, Patrick, Locomotive Superintendent, Great Northern Railway, Doncaster.

1875. Stoker, Frederick William, Messrs. Palmer's Shipbuilding and Iron Works, Jarrow.

1877. Stokes, Alfred Allen, The White House, Pauntley, Newent, Gloucestershire.

1877. Stothert, George Kelson, Steam Ship Works, Bristol.

1884. Stronge, Charles, Great Southern Railway, Locomotive Department, Buenos Aires; Post Office, Buenos Aires, Argentine Republic.

1865. Stroudley, William, Locomotive Superintendent, London Brighton and South Coast Railway, Brighton; and Bosvigo, Preston Park, Brighton.

1873. Strype, William George, The Murrough, Wicklow. [*Strype, Wicklow.*]

1878. Stuart, James, M.P., Professor of Mechanism in Cambridge University, Trinity College, Cambridge.

1882. Sturgeon, John, 4 Burlington Chambers, New Street, Birmingham. [*Air, Birmingham.*]

1882. Sugden, Thomas, Chadderton Iron Works, Irk Vale, Chadderton, near Manchester.

1861. Sumner, William, 2 Brazenose Street, Manchester.

1875. Sutcliffe, Frederic John Ramsbottom, Engineer, Low Moor Iron Works, near Bradford.

1883. Sutton, Joseph Walker, Messrs. Van Gelder Apsimon and Co., Victoria Works, Sowerby Bridge.

1880. Sutton, Thomas, Carriage and Wagon Superintendent, Furness Railway, Barrow-in-Furness.

1882. Swaine, John, Steel Company of Scotland, Newton, near Glasgow.

1884. Swan, Joseph Wilson, 57 Holborn Viaduct, London, E.C.; and Lauriston, Bromley, Kent.

1882. Swinburne, William, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne.

1864. Swindell, James Swindell Evers, 16 and 17 Exchange Buildings, Stephenson Place, Birmingham; and Clent House, Stourbridge.

1878. Taite, John Charles, Messrs. Taite and Carlton, 63 Queen Victoria Street, London, E.C. [1618.]

1882. Tandy, John O'Brien, London and North Western Railway, Locomotive Department, Crewe.

1875. Tangye, George, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham. [*Tangyes, Birmingham.*]

1861. Tangye, James, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham; and Aviary Cottage, Illogan, near Redruth.

1879. Tartt, William, Maythorn, Blindley Heath, Godstone, near Red Hill.

1876. Taunton, Richard Hobbs, Messrs. Taunton and Hayward, Star Tube Works, Heneage Street, Birmingham. [*Taunton, Birmingham.*]

1882. Tayler, Alexander James Wallis, Messrs. C. Tennant Sons and Co., San Fernando, Trinidad, West Indies.

1874. Taylor, Arthur, Manager, Lahat Tin Mines, Perak, viâ Penang; and 6 Queen Street Place, Upper Thames Street, London, E.C.

1874. Taylor, Henry Enfield, Mining Engineer, 15 Newgate Street, Chester.

1858. Taylor, James, Britannia Engine Works, Cleveland Street, Birkenhead. [*Britannia, Birkenhead.* 4045.]

1873. Taylor, John, Midland Foundry, Queen's Road, Nottingham.

1867. Taylor, Joseph, Corinthian Villa, Acock's Green, near Birmingham.

1875. Taylor, Joseph Samuel, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham. [*Derwent, Birmingham.*]

1874. Taylor, Percyvale, Messrs. Burthe and Taylor, 26 Rue de Caumartin, Paris.

1882. Taylor, Robert Henry, Regent House, Wilson Grove, Southsea, R.O., Portsmouth.

1882. Taylor, Thomas Albert Oakes, Messrs. Taylor Brothers and Co., Clarence Iron Works, Leeds.

1883. Taylor, William, Midland Foundry, Queen's Road, Nottingham.

1864. Tennant, Sir Charles, Bart. (*Life Member*), The Glen, Innerleithen, near Edinburgh.

1882. Terry, Stephen Harding, Local Government Board, Whitehall, London, S.W.

1877. Thom, William, Messrs. W. and J. Yates, Canal Foundry, Blackburn.

1867. Thomas, Joseph Lee, 2 Hanover Terrace, Ladbroke Square, Notting Hill, London, W.

1864. Thomas, Thomas, 10 Richmond Road, Roath, Cardiff.

1874. Thomas, William Henry, 15 Parliament Street, Westminster, S.W.

1875. Thompson, John, Highfields Boiler Works, Ettingshall, near Wolverhampton.

1883. Thompson, Richard Charles, Messrs. Robert Thompson and Sons, Southwick Shipbuilding Yard, Sunderland.

1857. Thompson, Robert, Victoria Chambers, Wigan ; and Standish, near Wigan.

1880. Thompson, Thomas William, Messrs. Thompson and Gough, South Mersey Ferries, Birkenhead.

1879. Thomson, David, Craighead, West Heath, Belvedere, Kent.

1875. Thomson, James McIntyre, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1868. Thomson, John, Messrs. John and James Thomson, Finnieston Engine Works, 36 Finnieston Street, Glasgow. [*Engineering, Glasgow.*]

1880. Thornbery, William Henry, Jun., Messrs. Henry Lea and Thornbery, 38 Bennett's Hill, Birmingham. [*Engineer, Birmingham.* 113.]

1868. Thornewill, Robert, Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1885. Thornley, George, Messrs. Buxton and Thornley, Waterloo Engineering Works, Burton-on-Trent.

1877. Thornton, Frederic William, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1882. Thornton, Hawthorn Robert, Lancashire and Yorkshire Railway, Locomotive Department, Victoria Station, Manchester.

1876. Thornycroft, John Isaac, Messrs. John I. Thornycroft and Co., Steam Yacht and Launch Builders, Church Wharf, Chiswick, London, W. [*Thornycroft, London.*]

1882. Thow, William, Locomotive Superintendent, South Australian Railways, Adelaide, South Australia : (or care of Joseph Meilbek, 7 Westminster Chambers, Victoria Street, Westminster, S.W.)

1884. Thwaites, Arthur Hirst, Vulcan Iron Works, Bradford. [*Thwaites, Bradford.* 325.]

1885. Tijou, William, Pinners Hall, 15 Great Winchester Street, London, E.C.

1885. Timmermans, François, Managing Director, Société anonyme des Ateliers de la Meuse, Liége, Belgium.

1884. Timmis, Illius Augustus, 2 Great George Street, Westminster, S.W. [*Timmis, London.*]

1886. Tipping, Henry, 55 Parliament Street, Westminster, S.W.

1875. Tomkins, William Steele, Messrs. Sharp Stewart and Co., Atlas Works, Manchester.

1857. Tomlinson, Joseph, Jun., 64 Priory Road, West Hampstead, London, N.W.

1883. Tower, Beauchamp, 19 Great George Street, Westminster, S.W.

1886. Towne, Henry Robinson, Yale and Towne Manufacturing Co., Stamford, Connecticut, United States.

1883. Trentham, William Henry, 33 Portland Road, Notting Hill, London, W.

1876. Trevithick, Richard Francis, Locomotive Superintendent, Ceylon Government Railways, Colombo, Ceylon: (or care of Mrs. Mary Trevithick, The Cliff, Penzance.)

1886. Trew, James Bradford, 6 Brunswick Place, Swansea.

1873. Trow, Joseph, Messrs. William Trow and Sons, Union Foundry, Wednesbury; and Victoria House, Holyhead Road, Wednesbury.

1885. Trueman, Thomas Brynalyn, Sola Works, Ferro Carril del Sud, care of T. W. Woodgate, 420 Rivadavia, Buenos Aires, Argentine Republic: (or care of Thomas R. Trueman, 7 Cambridge Villas, Twickenham.)

1883. Turnbull, Charles Henry, Mersey Dock Estate, Dock Yard, Liverpool.

1885. Turnbull, John, Jun., 255 Bath Street, Glasgow. [*Turbine, Glasgow.*]

1866. Turner, Frederick, Messrs. E. R. and F. Turner, St. Peter's Iron Works, Ipswich. [*Gippeswyk, Ipswich.*]

1886. Turner, George Reynolds, Vulcan Iron Works, Langley Mill, near Nottingham; and 81 Highgate Road, London, N.W.

1882. Turner, Thomas, New British Iron Works, Corngreaves, near Birmingham.

1886. Turner, Tom Newsum, Vulcan Iron Works, Langley Mill, near Nottingham.

1876. Turney, John, Messrs. Turney Brothers, Trent Bridge Leather Works, Nottingham. [*Turney, Nottingham.*]

1872. Turton, Thomas, Liverpool Forge Company, Brunswick Dock, Liverpool.

1867. Tweddell, Ralph Hart, 14 Delahay Street, Westminster, S.W. [*Tweddell, Westminster, London.*]

1882. Tweedy, John, Messrs. Wigham Richardson and Co., Newcastle-on-Tyne.

1856. Tyler, Sir Henry Whatley, K.C.B., M.P., Pymmes Park, Edmonton, Middlesex.

1877. Tylor, Joseph John, 11 Little Queen Street, Westminster, S.W.

1878. Tyson, Isaac Oliver, Ousegate Iron Works, Selby.

1875. Unsworth, Thomas, Carr Street, Blackfriars Street, Manchester. [*Machinist, Manchester.*]

1878. Unwin, William Cawthorne, Professor of Engineering, City and Guilds of London Central Institution, Exhibition Road, London, S.W.; and 7 Palace Gate Mansions, Kensington, London, W.

1875. Urquhart, Thomas, Locomotive Superintendent, Grazi and Tsaritsin Railway, Borisoglebsk, Russia: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1880. Valon, William Andrew McIntosh, Engineer, Corporation Gas and Water Works, Ramsgate. [*Valon, Ramsgate.*]

1885. Vaughan, William Henry, Royal Iron Works, West Gorton, Manchester. [*Pulleys, Openshaw.*]

1862. Vavasseur, Josiah, 28 Gravel Lane, Southwark, London, S.E.

1865. Vickers, Albert, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1861. Vickers, Thomas Edward, Messrs. Vickers Sons and Co., River Don Works, Sheffield.

1883. Waddell, James, Superintending Engineer, Netherlands India Steam Navigation Co., Soerabaya, Java; and 13 Austin Friars, London, E.C.

1856. Waddington, John, 35 King William Street, London Bridge, London, E.C.

1879. Wadia, Nowrosjee Nesserwanjee, Manager, Manockjee Petit Manufacturing Co., Tardeo, Bombay: (or care of Messrs. Hick Hargreaves and Co., Soho Iron Works, Bolton.) [*Wadia, Tardeo, Bombay.*]

1875. Wailes, John William, Patent Shaft Works, Wednesbury.

1884. Wailes, Thomas Waters, General Manager, Mountstuart Dry Dock and Engineering Works, Cardiff. [*Mountstuart, Cardiff.*]

1881. Wake, Henry Hay, Engineer to the River Wear Commission, Sunderland.

1882. Wakefield, William, Locomotive Superintendent, Dublin Wicklow and Wexford Railway, Grand Canal Street, Dublin.

1873. Waldenström, Eric Hugo, Manager, Broughton Copper Works, Broughton Road, Manchester.

1867. Walker, Benjamin, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds. [*Tannett Walker, Leeds.*]

1877. Walker, David, Superintendent of Engineering Workshops, King's College, Strand, London, W.C.

1875. Walker, George, 95 Leadenhall Street, London, E.C.

1875. Walker, John Scarisbrick, Messrs. J. S. Walker and Brother, Pagefield Iron Works, Wigan; and 3 Alexandra Road, Southport. [*Pagefield, Wigan.*]

1884. Walker, Sydney Ferris, 195 Severn Road, Cardiff [*Dynamo, Cardiff.*]; and Black Boy Yard, Nottingham. [*Dynamo, Nottingham.*]

1876. Walker, Thomas Ferdinand, Ship's Log Manufacturer, 58 Oxford Street, Birmingham.

1878. Walker, William, Kaliemaas, Alleyne Park, West Dulwich, London, S.E. [*Bromo, London.*]

1863. Walker, William Hugill, Messrs. Walker Eaton and Co., Wicker Iron Works, Sheffield.

1878. Walker, Zaccheus, Jun., Fox Hollies Hall, near Birmingham.

1881. Walkinshaw, Frank, care of the Hon. P. Ryrie, Hong Kong, China; and Hartley Grange, Winchfield.

1884. Wallace, John, Backworth Collieries, near Newcastle-on-Tyne.

1884. Wallau, Frederick Peter, Messrs. Harland and Wolff, Belfast.

1868. Wallis, Herbert, Mechanical Superintendent, Grand Trunk Railway, Montreal, Canada.

1865. Walpole, Thomas, Messrs. Ross and Walpole, North Wall Iron Works, Dublin. [*Iron, Dublin.* 311.]

1877. Walton, James, 28 Maryon Road, Charlton.

1881. Warburton, John Seaton, 19 Stanwick Road, West Kensington, London, W.

1882. Ward, Thomas Henry, Messrs. Lee Howl Ward and Howl, Tipton. [*Howl, Tipton.*]

1876. Ward, William Meese, Limerick Foundry, Great Bridge, Tipton.

1864. Warden, Walter Evers, Phœnix Bolt and Nut Works, Handsworth, near Birmingham. [*Bolts, Birmingham.*]

1856. Wardle, Charles Wetherell, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds. [*Manning, Leeds.*]

1882. Wardle, Edwin, Messrs. Manning Wardle and Co., Boyne Engine Works, Hunslet, Leeds.

1852. Warham, John R., Messrs. Thornewill and Warham, Burton Iron Works, Burton-on-Trent.

1881. Warham, Richard Landor, Messrs. W. and T. Avery, Digbeth, Birmingham.

1874. Warner, Edward, Leyton Villa, Gorleston, Yarmouth.

1885. Warren, Henry John, Jun., Engineer-in-Chief, Venezuela Panama Gold Mine, Venezuela, South America: (or Hayle, Cornwall.)

1885. Warren, William, Quebrada Railway Land and Copper Co., Tucacas, Venezuela; care of Messrs. Boulton and Co., Puerto Cabello, Venezuela, South America: (or care of Walter Ross, Hill Top, Blythe Hill, Catford, London, S.E.)

1882. Warsop, Henry, Clarendon Hotel, Nottingham.

1858. Waterhouse, Thomas (*Life Member*), Claremont Place, Sheffield.

1881. Watkins, Alfred, 2 Westcombe Park Road, Blackheath, London, S.E.

1862. Watkins, Richard, 94 Maida Vale, London, W.

1882. Watson, Henry Burnett, Messrs. Henry Watson and Son, High Bridge Works, Newcastle-on-Tyne. [*Watsons, Newcastle-on-Tyne.* 439.]

1879. Watson, William Renny, Messrs. Mirrlees Tait and Watson, Engineers, Glasgow.

1877. Watts, John, Broad Weir Engine Works, Bristol.

1877. Waugh, John, Chief Engineer, Yorkshire Boiler Insurance and Steam Users' Co., Sunbridge Chambers, Bradford. [*Boiler, Bradford.* 72.]

1886. Weatherburn, Robert, Locomotive Manager, Midland Railway Works, Kentish Town, London, N.W.

1878. Weatherhead, Patrick Lambert, Maschinenbau Actien Gesellschaft Vulcan, Bredow bei Stettin, Germany: (or care of W. Weatherhead, Castlegate, Berwick-on-Tweed.)

1884. Webb, Richard George, care of Messrs. John Fleming and Co., Bombay: (or care of Francis Webb, 31 Southampton Buildings, Chancery Lane, London, W.C.)

1883. Weck, Friedrich, Manager, Messrs. C. and W. Walker, Midland Iron Works, Donnington, near Newport, Shropshire.

1862. Wells, Charles, Moxley Iron and Steel Works, near Bilston.

1882. West, Charles Dickinson, Professor of Mechanical Engineering, Imperial College of Engineering, Tokio, Japan.

1876. West, Henry Hartley, Naval Architect and Engineer, 14 Castle Street, Liverpool.

1874. West, Nicholas James, Messrs. Harvey and Co., Hayle Foundry, Hayle.

1877. Western, Charles Robert, Broadway Chambers, Westminster, S.W. [*Donbowwow, London.* 3199.]

1877. Western, Maximilian Richard, care of Bombay Burmah Trading Corporation, Rangoon, British Burmah, India: (or care of Messrs. Wallace Brothers, 8 Austin Friars, London, E.C.)

1862. Westmacott, Percy Graham Buchanan, Sir W. G. Armstrong Mitchell and Co., Elswick Engine Works, Newcastle-on-Tyne; and Benwell Hill, Newcastle-on-Tyne.

1880. Westmoreland, John William Hudson, Lecturer on Engineering, University College, Nottingham.

1867. Weston, Thomas Aldridge, Yale and Towne Manufacturing Co., 62 Reade Street, New York: (or care of J. C. Mewburn, 169 Fleet Street, London, E.C.)

1880. Westwood, Joseph, Napier Yard, Millwall, London, E. [*Westwood, London.* 5065.]

1883. Wharton, Henry E., Engineering Manager, Basford Gas Works, Nottingham.

1881. Wharton, William Augustus, Assistant Engineer, Nottingham Corporation Water Works, St. Peter's Gate, Nottingham.

1884. Whieldon, John Henry, Campanhia do Beberibe, Rua Imperador, Pernambuco, Brazil: (or care of Ernest Whieldon, 1 Albion Place, High Street, Peckham, London, S.E.)

1882. White, Alfred Edward, Borough Engineer's Office, Town Hall, Hull.

1885. Whitehead, James George, Mechanical Engineer, Casilla No. 35, Callao, Peru.

1876. Whiteley, William, Messrs. William Whiteley and Sons, Prospect Iron Works, Lockwood, Huddersfield.

1884. Whithard, Brooke Middlemore, 18 Cockspur Street, London, S.W.: (or care of Rev. G. H. West, Ascham House, Bournemouth.)

1865. Whitley, Joseph, Railway Works, Hunslet Road, Leeds. [*Torpedo, Leeds.*]

1869. Whittem, Thomas Sibley, Wyken Colliery, Coventry.

1847. Whitworth, Sir Joseph, Bart., D.C.L., LL.D., F.R.S., Ashton Road, Openshaw, Manchester; Stancliffe, Matlock Bath; and 24 Great George Street, Westminster, S.W.

1878. Whytehead, Hugh Edward, North Staffordshire Tramways, Stoke-on-Trent.

1878. Wicks, Henry, Superintendent, Messrs. Burn and Co., Howrah Iron Works, Howrah, Bengal, India: (or care of Dr. Wicks, 1 Park Parade, Westmorland Road, Newcastle-on-Tyne.)

1868. Wicksteed, Joseph Hartley, Messrs. Joshua Buckton and Co., Well House Foundry, Meadow Road, Leeds.

1878. Widmark, Harald Wilhelm, Helsingborgs Mekaniska Verkstad, Helsingborg, Sweden.

1868. Wigram, Reginald, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1881. Wigzell, Eustace Ernest, 37 Walbrook, London, E.C. [*Wigzell, London.* 1844.]

1882. Wilder, John, Yield Hall Foundry, Reading.

1886. Wildridge, John, Consulting Engineer and Marine Superintendent, Eastern and Australian Steamship Co., 34 Leadenhall Street, London, E.C.; and care of Messrs. Gibbs Bright and Co., Pitt Street, Sydney, New South Wales.

1885. Willcox, Francis William, 45 West Sunniside, Sunderland.

1865. Williams, Edward, Cleveland Lodge, Middlesbrough.

1883. Williams, Edward Leader, Queen's Chambers, John Dalton Street, Manchester.

1884. Williams, John Begby, Messrs. William Gray and Co., Central Marine Engineering Works, West Hartlepool.

1884. Williams, John Rhys, Rhymney Iron Works, Rhymney, R.S.O., Monmouthshire.

1885. Williams, Nicholas Thomas, Mining Engineer, Brazilian Exploration Co., 9 New Broad Street, London, E.C.

1847. Williams, Richard, Patent Shaft Works, Wednesbury.

1881. Williams, William Freke Maxwell, 35 Queen Victoria Street, London, E.C.

1873. Williams, William Lawrence, 3 Victoria Street, Westminster, S.W. [*Snowdon, London.*]

1883. Williamson, Richard, Messrs. Richard Williamson and Son, Iron Shipbuilding Yard, Workington.
1870. Willman, Charles, 26 Albert Road, Middlesbrough.
1883. Willmott, Arthur Wellesley Westmacott, Kiangnan Arsenal, Shanghai, China.
1884. Willock, Capt. Harry Borlase, R.E., War Office, Whitehall, London, S.W.
1878. Wilson, Alexander, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1884. Wilson, Alexander, Addington House, Bow Road, London, E.
1882. Wilson, Alexander Basil, Holywood, Belfast. [*Wilson, Holywood.* 201.]
1872. Wilson, Alfred, Gas Furnace Engineer, Stafford. [*Wilson, Stafford.*]
1883. Wilson, George Prangley, Assistant Manager, Messrs. Charles Cammell and Co., Cyclops Steel and Iron Works, Sheffield.
1867. Wilson, Henry, Phœnix Brass Works, Stockton-on-Tees.
1884. Wilson, James, Chief Engineer of the Daira Sanieh, Egypt; Cairo, Egypt.
1881. Wilson, John, Engineer, Great Eastern Railway, Liverpool Street Station, London, E.C. [*Wilson, Eastern, London.*]
1863. Wilson, John Charles, 5 Westminster Chambers, Victoria Street, Westminster, S.W. [*Palacol, London.*]
1879. Wilson, Joseph William, Principal of School of Practical Engineering, Crystal Palace, Sydenham, London, S.E.
1880. Wilson, Robert, 24 Poultry, London, E.C.
1883. Wilson, Robert, Messrs. Nasmyth Wilson and Co., Bridgewater Foundry, Patricroft, near Manchester.
1884. Wilson, Thomas, Manager, Wallsend Slipway and Engineering Works, Wallsend, near Newcastle-on-Tyne.
1873. Wilson, Thomas Sipling, British Vice-Consul, Brettesnœs, Lofoten Islands, Norway; and Messrs. Holroyd Horsfield and Wilson, Larchfield Foundry, Leeds: (or care of Messrs. James Bischoff and Sons, 10 St. Helen's Place, London, E.C.)
1881. Wilson, Wesley William, Messrs. A. Guinness Son and Co., St. James' Gate Brewery, Dublin.
1886. Windsor, Edwin Wells, 1 Rue du Hameau des Bronettes, Rouen, France.
1872. Winstanley, Robert, Mining Engineer, 28 Deansgate, Manchester.
1872. Wise, William Lloyd, 46 Lincoln's Inn Fields, London, W.C. [*Lloydwise, London.* 2766.]
1871. Withy, Edward, Avon Villa, Parnell, Auckland, New Zealand.
1884. Withy, Henry, Messrs. Withy and Co., Middleton Ship Yard, West Hartlepool. [*Withy, West Hartlepool.* 4.]
1878. Wolfe, John Edward, General Manager, Alagoas Railway, Maccio, Brazil: (or care of Rev. Prebendary Wolfe, Arthington, Torquay.)

1878. Wolfenden, Richard, Chief Engineer, Chinese Cruiser "Yang Wei"; care of Chinese Customs Agency, Hong Kong, China; and 11 Grafton Street, Moss Side, Manchester.

1878. Wolfenden, Robert, Revenue Cutter "Ling Fêng," care of Commissioner of Customs, Amoy, China.

1886. Wolff, Henri Michel, Hafna Lead Mining and Smelting Works, Llanrwst, North Wales.

1881. Wood, Edward Malcolm, 2 Westminster Chambers, Victoria Street, Westminster, S.W.

1880. Wood, John Mackworth, Engineer's Department, New River Water Works, Clerkenwell, London, E.C.

1868. Wood, Lindsay, Mining Engineer, Southhill, near Chester-le-Street.

1885. Wood, Robert Henry, Messrs. Tannett Walker and Co., Goodman Street Works, Hunslet, Leeds; and 15 Bainbrigge Road, Headingley, Leeds.

1884. Wood, Sidney Prescott, care of H. W. Little, Messrs. McKenzie and Holland, Vulcan Iron Works, Worcester.

1885. Wood, Thomas, Ebbw Vale Steel Iron and Coal Works, Ebbw Vale, R.S.O., Monmouthshire.

1882. Woodall, Corbet, Palace Chambers, 9 Bridge Street, Westminster, S.W.

1884. Woodward, William, Engineer and Manager, Corporation Gas Works, Bury, Lancashire. [*Woodward, Bury.*]

1885. Wootton, Albert, Falcon Engine and Car Works, Loughborough.

1874. Worsdell, Thomas William, Locomotive Superintendent, North Eastern Railway, Gateshead. [*Locomotive, Gateshead.*]

1884. Worssam, Charles Smith, Messrs. Samuel Worssam and Co., Oakley Works, Chelsea, London, S.W.

1877. Worssam, Henry John, Messrs. G. J. Worssam and Son, Wenlock Road, City Road, London, N. [*Massrow, London.* 6656.]

1876. Worssam, Samuel William, Oakley Works, King's Road, Chelsea, London, S.W.

1886. Worthington, Charles Campbell, Messrs. Henry R. Worthington, Hydraulic Works, 145 Broadway, New York, United States.

1860. Worthington, Samuel Barton, Consulting Engineer, 33 Princess Street, Manchester; and 12 York Place, Oxford Road, Manchester.

1866. Wren, Henry, Messrs. Henry Wren and Co., London Road Iron Works, Manchester. [*Henry Wren, Manchester.*]

1881. Wrench, John Mervyn, District Engineer, Indian Midland Railway, Bhilsa, viâ Bhopal, Central India.

1881. Wright, Benjamin Frederick, Locomotive and Carriage Superintendent, Japanese Government Railways, Kobe, Japan: (or care of the Hong Kong and Shanghai Bank, 31 Lombard Street, London, E.C.)

1870. Wright, George Benjamin, Prince's Square, Wolverhampton.

1878. Wright, Rev. George Howard, 21 Clanricarde Gardens, Bayswater, London, W.

1876. Wright, James, Messrs. Ashmore Benson Pease and Co., Stockton-on-Tees. [*Wright, Gasholder, Stockton.* 12.]

1867. Wright, John Roper, Messrs. Wright Buttler and Co., Elba Steel Works, Gower Road, near Swansea.

1859. Wright, Joseph, Metropolitan Railway - Carriage and Wagon Co., Saltley Works, Birmingham; and 85 Gracechurch Street, London, E.C.

1860. Wright, Joseph, Neptune Forge, Chain and Anchor Works, Tipton; and Lawnswood, Alexandra Road, Upper Norwood, London, S.E. [*Wright, Tipton.*]

1878. Wright, William Barton, Locomotive Superintendent, Lancashire and Yorkshire Railway, Victoria Station, Manchester.

1871. Wrightson, Thomas, Messrs. Head Wrightson and Co., Teesdale Iron Works, Stockton-on-Tees.

1886. Wylie, James, Superintendent Engineer, Sugar Estates, California Station, Trinidad.

1865. Wyllie, Andrew, Messrs. Forrester and Co., Vauxhall Foundry, Vauxhall Road, Liverpool; and 1 Leicester Street, Southport.

1883. Wyllie, Robert, Manager, Messrs. Thomas Richardson and Sons, Hartlepool Iron Works, Hartlepool.

1883. Wynne-Edwards, Thomas Alured, Agricultural Engineering Works, Denbigh. [*Foundry, Denbigh.*]

1877. Wyvill, Frederic Christopher, 5 Piazza della Scala, Milan, Italy.

1878. Yates, Henry, Brantford, Ontario, Canada.

1882. Yates, Herbert Rushton, Assistant Engineer, Michigan Air Line Railway Extension, Pontiac, Michigan, United States: (or care of Henry Yates, Brantford, Ontario, Canada.)

1881. Yates, Louis Edmund Hasselts, Locomotive Superintendent, Naraingunge Dacca and Mymensing State Railway, Dacca, Bengal: (or care of Rev. H. W. Yates, 98 Lansdowne Place, Brighton.)

1880. Yates, William, Locomotive Works, Lancashire and Yorkshire Railway, Miles Platting, Manchester.

1885. Yeo, George Jope, Engineer, Gas Works, Shanghai, China: (or care of Mrs. Knowles, Fern Bank, Alexandra Road, Manchester.)

1880. York, Francis Colin, Buenos Aires and Pacific Railway, Mercedes, Buenos Aires, Argentine Republic: (or care of Messrs. Samuel York and Co., Snow Hill, Wolverhampton.)

1879. Young, George Scholey, Messrs. T. A. Young and Son, Orchard Place, Blackwall, London, E.

1874. Young, James, Managing Engineer, Lambton Colliery Works, Fence Houses.

1879. Young, James, Low Moor Iron Works, near Bradford.

1881. Younger, Robert, Messrs. R. and W. Hawthorn Leslie and Co., St. Peter's Works, Newcastle-on-Tyne.

1885. Zimmer, George Friedrich, care of J. Harrison Carter, 82 Mark Lane, London, E.C.

ASSOCIATES.

1880. Allen, William Edgar, Imperial Steel Works, Savile Street, Sheffield.

1880. Bagshawe, Washington, Monk Bridge Iron Works, Leeds.

1881. Barcroft, Henry, Bessbrook Spinning Works, County Armagh, Ireland.

1886. Bennison, William Clyburn, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1879. Clowes, Edward Arnott, Messrs. William Clowes and Sons, Duke Street, Stamford Street, London, S.E. [*Clowes, London.* 4558.]

1882. Drury, Robert Francis, George Street, Sheffield.

1883. Fairholme, Capt. Charles, R.N., Heberlein Self-acting Railway Brake Co., 18 St. Dunstan's Hill, London, E.C.

1886. Fisher, Harry, Messrs. Burys and Co., Regent Steel Works, Sheffield.

1865. Gössell, Otto, 41 Moorgate Street, London, E.C.

1880. Haggie, David Henry, Wearmouth Rope Works, Sunderland.

1884. Hasluck, Paul Nooncree, 309 Regent Street, London, W.

1884. Jackson, Edward, Midland Railway-Carriage and Wagon Works, Birmingham. [*Wagon, Birmingham.*]

1882. Jackson, William, Kingston Cotton Mill, Hull.

1884. Livesey, Joseph Montague, Stourton Hall, Horncastle.

1865. Longsdon, Alfred, 9 New Broad Street, London, E.C.

1881. Lowood, John Grayson, Gannister Works, Attercliffe Road, Sheffield. [*Lowood, Sheffield.*]

1883. Macilraith, James, 92 Regent Street, Glasgow. [*Macilraith, Glasgow.*]

1886. Mackenzie, Keith Ronald, Gillotts, Henley-on-Thames.

1868. Matthews, Thomas Bright, Messrs. Turton Brothers and Matthews, Phœnix Steel Works, Sheffield. [*Matthews, Sheffield.*]

1885. Moser, Charles Henry, Messrs. Moser and Sons, 178 High Street, Southwark, London, S.E. [*Moserson, London.* 4563.]

1886. Newton, Henry Edward, 6 Bream's Buildings, Chancery Lane, London, E.C.

1874. Paget, Berkeley, Low Moor Iron Office, 2 Laurence Pountney Hill, Cannon Street, London, E.C. [*Gryphon, London.*]

1886. Peacock, William J. P., Wells Street, Oxford Street, London, W.; and 41 St. James' Street, London, S.W.

1884. Phillips, Richard Morgan, care of Messrs. Emile Des Marets and Co., 14 Stone Street, New York, United States.

1886. Raven, Henry Baldwin, Messrs. Hare and Co., 19 Surrey Street, Strand, London, W.C.

1882. Ridehalgh, George John Miller, Fell Foot, Newby Bridge, Ulverston.

1883. Sandham, Henry, Keeper, Science and Art Department, South Kensington Museum, London, S.W.

1875. Schofield, Christopher J., Vitriol and Alkali Works, Clayton, near Manchester.

1878. Stalbridge, The Right Hon. Lord, 12 Upper Brook Street, Grosvenor Square, London, W.

1886. Stumore, Frederick, 34 Leadenhall Street, London, E.C.

1884. Tilfourd, George, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1869. Varley, John, Leeds Forge, Leeds.

1878. Watson, Joseph, Patent Office, 25 Southampton Buildings, London, W.C.

1883. Williamson, Robert S., Cannock and Rugeley Collieries, Hednesford, near Stafford.

GRADUATES.

1884. Adam, Frank, Sir W. G. Armstrong Mitchell and Co., Elswick, Newcastle-on-Tyne.

1885. Addis, Frederick Henry, Ajmere, India: (or care of Messrs. Grindlay and Co., 55 Parliament Street, London, S.W.)

1885. Allcard, Harry, Messrs. Easterbrook Allcard and Wild, Albert Works, Penistone Road, Sheffield.

1874. Allen, Frank, Messrs. Allen Alderson and Co., Gracechurch Street, Alexandria: (or care of Messrs. Stafford Allen and Sons, 7 Cowper Street, Finsbury, London, E.C.)

1882. Allgood, Robert Lancelot, Nunwick, Humshaugh, R.S.O., Northumberland.

1885. Amos, Ewart Charles, Rosslyn Grove, Hampstead, London, N.W.

1880. Anderson, Edward William, Messrs. Easton and Anderson, Erith Iron Works, Erith, S.O., Kent.

1882. Anderson, William, North Eastern Railway, Locomotive Department, York.

1878. Appleby, Charles, Jun., 89 Cannon Street, London, E.C. [*Appleby's, London.* 1731.]

1883. Appleby, Percy Vavasseur, Messrs. Appleby Brothers, 89 Cannon Street, London, E.C.

1878. Armstrong, Joseph, Great Western Railway, Stafford Road Works, Wolverhampton.

1886. Atkey, Albert Reuben, Corporation Water Works, Nottingham.

1869. Bainbridge, Emerson, Nunnery Colliery Offices, New Haymarket, Sheffield.

1882. Barstow, Thomas Hulme, Railway Manager, Picton, Marlborough, New Zealand.

1881. Beesley, David Stanley, Messrs. D. S. Beesley and Co., Bracebridge Works, Bracebridge Street, Birmingham.

1884. Bell, Robert Arthur, 509 Ashton Old Road, Openshaw, Manchester.

1880. Birkett, Herbert, care of Messrs. S. G. Sansinena and Co., 64 Peru, Buenos Aires, Argentine Republic; and 62 Green Street, Grosvenor Square, London, W.

1884. Bocquet, Harry, care of Arthur E. Shaw, Estacion Central, Paseo de Julio, Buenos Aires, Argentine Republic: (or care of Joseph Harrison, Llanwye, Hampton Park, Hereford.)

1883. Booth, William Stanway, Messrs. Vivian and Sons, Hafod Foundry, Swansea.

1886. Bourne, Thomas Johnstone, Southborough, Tunbridge Wells.

1878. Brooke, Arthur, General Post Office, Auckland, New Zealand: (or care of Miss Helen Brooke, Sunnymead, The Rise, Sidcup, S.O., Kent.)

1886. Brounlie, John, 9 Victoria Chambers, Victoria Street, Westminster, S.W.

1886. Brown, Andrew, 5 Glenthorn Road, Hammersmith, London, W.

1880. Buckle, William Harry Ray, Union Dock, Limehouse, London, E. [*Buckle, Fletchdock, London.* 5109.]

1886. Budenberg, Christian Frederick, 25 Demesne Road, Whalley Range, Manchester.

1879. Burnet, Lindsay, Moore Park Boiler Works, Govan, near Glasgow. [*Burnet, Glasgow.* 1513.]

1885. Burrowes, Gerald Vaughan, Halmirah, Golahghaut, Assam, India: (or care of Miss Burrowes, 5 West Cromwell Road, London, S.W.)

1884. Butler, Hugh Myddleton, Kirkstall Forge, near Leeds.

1886. Cairnes, Frederick Evelyn, care of R. Price-Williams, North Brow, Primrose Hill, London, N.W.

1883. Cairns, The Hon. Herbert John, 48 Park Terrace, New Brompton, Chatham.

1886. Carver, Charles, Lace Machine Works, Alfred Street, Nottingham.

1885. Clarke, Leslie, 132 Westbourne Terrace, Hyde Park, London, W.

1883. Clench, Frederick McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1881. Clench, Gordon McDakin, Messrs. Robey and Co., Globe Iron Works, Lincoln.

1885. Clift, Leslie Everitt, Fernbank, Pittville, Cheltenham.

1885. Clifton, George Bellamy, Great Western Railway Works, Swindon.

1883. Clinkskill, Alfred Alphonse Rouff, 1 Holland Place, St. Vincent Street, Glasgow.

1886. Conyers, Sidney Ward, 36 Wynyard Square, Sydney, New South Wales.

1883. Cotton, Henry Streatfeild, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.; and 25 Vincent Square, Westminster, S.W.

1885. Crosta, Lorenzo William, Messrs. R. R. Newlove and Co., Crown Iron Works, Crocus Street, Nottingham; and 21 Mayfield Grove, Nottingham.

1876. Davis, Joseph, Lancashire and Yorkshire Railway, Engineer's Office, Manchester.

1875. Dawson, Edward, Messrs. Forster Brown and Rees, Guild Hall Chambers, Cardiff.

1884. Dixon, John, 115 York Place, Harpurhey, R. O., Manchester.

1868. Dugard, William Henry, Messrs. Dugard Brothers, Vulcan Rolling Mills, Bridge Street West, Summer Lane, Birmingham. [*Vulcan, Birmingham.*]

1885. Dutt, Jodoo Nauth, 8 Mecklenburgh Street, London, W.C.

1886. Duvall, Charles Anthony, care of John W. Newall, Arnold Road, Bow, London, E.

1885. Edwards, Walter Cleeve, Assistant Engineer, Wellington and Manawatu Railway, Wellington, New Zealand.

1875. Ffolkes, Martin William Brown, 28 Davies Street, Grosvenor Square, London, W.

1883. Gibbons, Charles Kenrick, 27 Choppington Street, Newcastle-on-Tyne.

1885. Grant, John Macpherson, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne; and 63 Westmorland Road, Newcastle-on-Tyne.

1886. Grant, Percy, South Eastern Railway, Ashford, Kent; and Surrey Villa, Ashford, Kent.

1878. Greig, Alfred, Messrs. John Fowler and Co., Steam Plough and Locomotive Works, Leeds.

1886. Halsey, William Stirling, Jun., Egerton Woollen Mills, Dhariwal, Amritsar, Punjaub, India.

1885. Head, Archibald Potter, 19 Gloucester Terrace, Westmorland Road, Newcastle-on-Tyne.

1882. Heath, Ashton Marler, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1877. Heaton, Arthur, Messrs. Heaton and Dugard, Metal and Wire Works, Shadwell Street, Birmingham. [*Heagard, Birmingham.*]

1874. Hedley, Thomas, 118 Holt Road, Liverpool.

1883. Hill, John Kershaw, Engineer and Manager, West Surrey Water Works, High Street, Walton-on-Thames.

1886. Holdsworth, Francis Matthew, Messrs. Taylor and Challen, Derwent Foundry, 60 and 62 Constitution Hill, Birmingham.

1867. Holland, George, Mechanical Department, Grand Trunk Railway, Montreal, Canada.

1885. Holroyd, John Herbert, care of Mrs. Collinson, 1 The Woodlands, Victoria Park, Manchester.

1884. Holt, Follett, London and South Western Railway, Locomotive Department, Nine Elms, London, S.W.

1886. Hosgood, John Howell, Locomotive Department, Taff Vale Railway, Cardiff.

1883. Howard, Harry James, Messrs. Colman's Mustard Mills, Carrow Works, Norwich.

1879. Howard, J. Harold, Britannia Iron Works, Bedford.

1883. Hulse, Joseph Whitworth, Messrs. Hulse and Co., Ordsal Tool Works Regent Bridge, Salford, Manchester.

1883. Keen, Francis Watkins, Patent Nut and Bolt Works, Smethwick, near Birmingham.

1885. Keyworth, Thomas Egerton, Messrs. Clayton and Shuttleworth, Stamp End Works, Lincoln; and 38 Monks Road, Lincoln.

1884. King, Charles Philip, Royston House, Upper Richmond Road, Putney, London, S.W.

1885. Laidler, Thomas, Meldon House, Leopold Street, Burdett Road, London, E. [*Gravitation, London.*]

1883. Lander, Philip Vincent, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1881. Lawson, James Ibbs, Assistant Engineer, New Zealand Railways, Invercargill, Otago, New Zealand.

1884. Lepan, René, Lead and Tin Rolling Mills and Pipe Works, Lille (Nord), France.

1886. Lewis, William Thomas, Jun., Engineer's Office, Bute Docks, Cardiff.

1879. Lowthian, George, 35A Great George Street, Westminster, S.W.; and 58 Blenheim Crescent, Notting Hill, London, W.

1886. Lucy, William Theodore, Messrs. William Lucy and Co., Eagle Iron Works, Oxford; and Thornleigh, Woodstock Road, Oxford.

1881. Macdonald, Ranald Mackintosh, Messrs. Booth Macdonald and Co., Carlyle Engineering and Implement Works, Christchurch, New Zealand; and P.O. Box 89, Christchurch, New Zealand.

1883. Mackenzie, Thomas Brown, Messrs. J. Copeland and Co., Pulteney Street Engine Works, Glasgow; and 342 Duke Street, Glasgow.

1883. Malan, Ernest de Mérindol, Howden.

1868. Mappin, Frank, Messrs. Thomas Turton and Sons, Sheaf Works, Sheffield.

1883. Marrack, Philip, R.N., H.M.S. "Alexandra," Malta; and Burraton, Saltash, R.S.O., Cornwall.

1882. Martindale, Warine Ben Hay, Southern Mahratta Railway, Haveri, Bombay Presidency, India; and 21 Kensington Gardens Square, London, W.

1886. Mattos, Alvaro Gomes de, 1 Bedford Place, Russell Square, London, W.C.

1881. Milles, Robert Sydney. Engineer's Office, Launceston and Scottsdale Railway, Launceston, Tasmania: (or, care of Rev. Thomas Milles, St. Margaret's, Collier Street, Marden.)

1867. Mitchell, John, Swaithe Hall, Barnsley.

1868. Moor, William, Jun., Cross Lanes, Hetton-le-Hole, near Fence Houses.

1885. Mudie, Charles, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.

1878. Newall, John Walker, Arnold Road, Bow, London, E.

1882. Noble, Saxton William Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1883. O'Connor, John Frederick, 6 East Seventeenth Street, New York.

1883. Osborn, William Fawcett, Messrs. Samuel Osborn and Co., Clyde Steel and Iron Works, Sheffield.

1881. Oswell, William St. John, 27 Leadenhall Street, London, E.C.
1883. Palchoudhuri, Bipradas, Moheshgunj Factory, Krishnugher, Bengal.
1884. Philipson, William, Messrs. Atkinson and Philipson, 27 Pilgrim Street, Newcastle-on-Tyne. [*Carriage, Newcastle-on-Tyne.* 415.]
1884. Reynolds, Thomas Blair, 5 Great George Street, Westminster, S.W.
1885. Ripley, Philip Edward, Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich.
1881. Rogers, Philip Powys, Assistant Engineer, Wardha Coal State Railway, Warora, Central Provinces, India; care of Messrs. Grindlay Groom and Co., Bombay, India.
1884. Roux, Paul Louis, 54 Boulevard du Temple, Paris.
1882. Sanchez, Juan Emilio, 31 Rivadavia, Buenos Aires, Argentine Republic: (or care of Mateo Clark, 4 St. Mary Axe, London, E.C.)
1882. Scott, Charles Herbert, Bessemer Steel Works, Sheffield.
1881. Scott, Ernest, Close Works, Newcastle-on-Tyne. [*Eseo, Newcastle-on-Tyne.* 432.]
1886. Silcock, Charles Whitbread, Watling Works, Stony Stratford.
1883. Simpson, Charles Liddell, Messrs. Simpson and Co., Engine Works, 101 Grosvenor Road, Pimlico, London, S.W.
1884. Sollory, George Henry, Messrs. H. Sollory and Son, 2 Mount Street, Nottingham.
1884. Streatfeild, Mervyn Armytage, Chested, Chiddingstone, Eden-Bridge, Kent.
1883. Swale, Gerald, Ingfield Hall, Settle.
1885. Tangye, John Henry, Messrs. Tangyes, Cornwall Works, Soho, near Birmingham.
1884. Taylor, Joseph, 1 Somerville Terrace, Ennersdale Road, Lewisham, London, S.E.
1884. Taylor, Maurice, Ateliers des Forges et Chantiers de la Méditerranée, Marseille, France.
1884. Templeton, Edwin Arthur Slade, 42 Boscombe Road, Shepherd's Bush, London, W.
1878. Waddington, John, Jun., 35 King William Street, London Bridge, London, E.C.
1882. Wailes, George Herbert, St. Andrews, Watford, Herts.
1885. Wakefield, William Marsden, Kurneh, Lewisham Park, Lady Well, London, S.E.
1884. Walker, Matthew, 22 Burns Street, Nottingham.
1884. Walker, Ralph Teasdale, 44 Princes Street, Pollokshields, R.O. Glasgow.
1886. Walker, Robert John, Superintending Engineer, Urr Viaduct, Dalbeattie.
1886. Warren, Frank Llewellyn, Messrs. Humphrys Tennant and Co., Deptford Pier, London, S.E.

1886. Wesley, Joseph A., Clarke's Crank and Forge Works, Lincoln.

1883. Westmacott, Henry Armstrong, Sir W. G. Armstrong Mitchell and Co., Elswick Works, Newcastle-on-Tyne.

1880. Weymouth, Francis Marten, Messrs. Crompton and Co., Arc Works, Chelmsford; and Vine Cottage, Baddow Road, Chelmsford.

1879. Wood, Edward Walter Naylor, Resident Engineer, Great Indian Peninsula Railway, Sholapur, India.

1882. Woollcombe, Reginald, Assistant Engineer, Public Works Department, India; care of Messrs. King King and Co., Bombay.

1885. Wray, Charles Drinkwater, Government House, Jersey.

1884. Yokoi, Saku, 110 Rue Jurenne, Paris.

THE INSTITUTION OF MECHANICAL ENGINEERS.

Memorandum of Association.

August 1878.

1st. The name of the Association is "The Institution of Mechanical Engineers."

2nd. The Registered Office of the Association will be situate in England.

3rd. The objects for which the Association is established are:—

(a.) To promote the science and practice of Mechanical Engineering and all branches of mechanical construction, and to give an impulse to inventions likely to be useful to the Members of the Institution and to the community at large.

(b.) To enable Mechanical Engineers to meet and to correspond, and to facilitate the interchange of ideas respecting improvements in the various branches of mechanical science, and the publication and communication of information on such subjects.

(c.) To acquire and dispose of property for the purposes aforesaid.

(d.) To do all other things incidental or conducive to the attainment of the above objects or any of them.

4th. The income and property of the Association, from whatever source derived, shall be applied solely towards the promotion of the objects of the Association as set forth in this Memorandum of Association, and no portion thereof shall be paid or transferred directly or indirectly, by way of dividend, bonus, or otherwise howsoever, by way of profit to the persons who at any time are or have been Members of the Association, or to any of them, or to any person claiming through any of them: Provided that nothing herein contained shall prevent the payment in good faith of remuneration to any officers or servants of the Association, or to any Member of the Association, or other person, in return for any services rendered to the Association, or prevent the giving of privileges to the Members of the Association in attending the meetings of the Association, or prevent the borrowing of money (under such powers as the Association and the Council thereof may possess) from any Member of the Association, at a rate of interest not greater than five per cent. per annum.

5th. The fourth paragraph of this Memorandum is a condition on which a licence is granted by the Board of Trade to the Association in pursuance of Section 23 of the Companies Act 1867. For the purpose of preventing any evasion of the terms of the said fourth paragraph, the Board of Trade may from time to time, on the application of any Member of the Association, impose further conditions, which shall be duly observed by the Association.

6th. If the Association act in contravention of the fourth paragraph of this Memorandum, or of any such further conditions, the liability of every Member of the Council shall be unlimited; and the liability of every Member of the Association who has received any such dividend, bonus, or other profit as aforesaid, shall likewise be unlimited.

7th. Every Member of the Association undertakes to contribute to the Assets of the Association in the event of the same being wound up during the time that he is a Member, or within one

year afterwards, for payment of the debts and liabilities of the Association contracted before the time at which he ceases to be a Member, and of the costs, charges, and expenses for winding up the same, and for the adjustment of the rights of the contributories amongst themselves, such amount as may be required not exceeding Five Shillings, or in case of his liability becoming unlimited such other amount as may be required in pursuance of the last preceding paragraph of this Memorandum.

8th. If upon the winding up or dissolution of the Association there remains, after the satisfaction of all its debts and liabilities, any property whatsoever, the same shall not be paid to or distributed among the Members of the Association, but shall be given or transferred to some other Institution or Institutions having objects similar to the objects of the Association, to be determined by the Members of the Association at or before the time of dissolution; or in default thereof, by such Judge of the High Court of Justice as may have or acquire jurisdiction in the matter.

Articles of Association.

August 1878.

INTRODUCTION.

Whereas an Association (hereinafter called "the existing Institution") called "The Institution of Mechanical Engineers" has long existed for objects similar to the objects expressed in the Memorandum of Association of the Association (hereinafter called "the Institution") to which these Articles apply, and the existing Institution consists of Members, Graduates, Associates, and Honorary Life Members, and is possessed of books, drawings, and property used for the objects aforesaid;

And whereas the Institution is formed for furthering and extending the objects of the existing Institution, by a registered Association, under the Companies Acts 1862 and 1867; and terms used in these Articles are intended to have the same respective meanings as they have when used in those Acts, and words implying the singular number are intended to include the plural number, and *vice versâ*;

Now therefore it is hereby agreed as follows:—

CONSTITUTION.

1. For the purpose of registration the number of Members of the Institution is unlimited.

MEMBERS.

2. The subscribers of the Memorandum of Association, and such other persons as shall be admitted in accordance with these Articles, and none others, shall be Members of the Institution, and be entered on the register as such.

3. Any person may become a Member of the Institution who, being a Member of the existing Institution, shall agree to transfer his membership of the existing Institution, and all rights and obligations incidental thereto, to the Institution, and to be registered as a Member of the Institution accordingly.

4. Any person may become a Member of the Institution who shall be qualified and elected as hereinafter mentioned, and shall agree to become such Member, and shall pay the entrance fee and first subscription accordingly.

5. The rights and privileges of every Member of the Institution shall be personal to himself, and shall not be transferable or transmissible by his own act or by operation of law.

QUALIFICATION AND ELECTION OF MEMBERS.

6. The qualification of Members shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

7. The election of Members shall be conducted as prescribed by the Bye-laws from time to time in force, as provided by the Articles.

GRADUATES, ASSOCIATES, AND HONORARY LIFE MEMBERS.

8. Any person may become a Graduate, Associate, or Honorary Life Member of the Institution, who, being already a Graduate, Associate, or Honorary Life Member of the existing Institution, shall agree to transfer his interest in the existing Institution, and all rights and obligations incidental thereto, to the Institution.

9. The Institution may admit such other persons as may be hereafter qualified and elected in that behalf as Graduates, Associates, and Honorary Life Members respectively of the Institution, and may confer upon them such privileges as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Graduate, Associate, or Honorary Life Member shall be deemed to be a Member within the meaning of the Articles.

10. The qualification and mode of election of Graduates, Associates, and Honorary Life Members, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

ENTRANCE FEES AND SUBSCRIPTIONS.

11. The Entrance Fees and Subscriptions of Members, Graduates, and Associates, shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles: Provided that no Entrance Fee shall be payable by a Member, Graduate, or Associate of the existing Institution.

EXPULSION.

12. If any Member, Graduate, or Associate shall leave his subscription in arrear for two years, and shall fail to pay such arrears within three months after a written application has been sent to him by the Secretary, his name may be struck off the list of Members, Graduates, or Associates, as the case may be, by the Council, at any time afterwards, and he shall thereupon cease to

have any rights as a Member, Graduate, or Associate, but he shall nevertheless continue liable to pay the arrears of subscription due at the time of his name being so struck off: Provided always, that this regulation shall not be construed to compel the Council to remove any name if they shall be satisfied the same ought to be retained.

13. The Council may refuse to continue to receive the subscriptions of any person who shall have wilfully acted in contravention of the regulations of the Institution, or who shall in the opinion of the Council have been guilty of such conduct as shall have rendered him unfit to continue to belong to the Institution; and may remove his name from the list of Members, Graduates, or Associates (as the case may be), and such person shall thereupon cease to be a Member, Graduate, or Associate (as the case may be) of the Institution.

GENERAL MEETINGS.

14. The first General Meeting shall be held on such day, within four months of the registration of the Institution, as the Council shall determine. Subsequent General Meetings shall consist of the Ordinary Meetings, the Annual General Meeting, and of Special Meetings as hereinafter defined.

15. The Annual General Meeting shall take place in London in one of the first four months of every year. The Ordinary Meetings shall take place at such times and places as the Council shall determine.

16. A Special Meeting may be convened at any time by the Council, and shall be convened by them whenever a requisition signed by twenty Members of the Institution, specifying the object of the Meeting, is left with the Secretary. If for fourteen days after the delivery of such requisition a Meeting be not convened in accordance therewith, the Requisitionists or any twenty Members

of the Institution may convene a Special Meeting in accordance with the requisition. All Special Meetings shall be held in London.

17. Seven clear days' notice of every Meeting, specifying generally the nature of any special business to be transacted at any Meeting, shall be given to every Member of the Institution, and no other special business shall be transacted at such Meeting; but the non-receipt of such notice shall not invalidate the proceedings of such Meeting. No notice of the business to be transacted (other than such ballot lists as may be requisite in case of elections) shall be required in the absence of special business.

18. Special business shall include all business for transaction at a Special Meeting, and all business for transaction at every other Meeting, with the exception of the reading and confirmation of the Minutes of the previous Meeting, the election of Members, Graduates, and Associates, and the reading and discussion of communications as prescribed by the Bye-laws, or any regulations of the Council made in accordance with the Bye-laws.

PROCEEDINGS AT GENERAL MEETINGS.

19. Twenty Members shall constitute a quorum for the purpose of a Meeting other than a Special Meeting. Thirty Members shall constitute a quorum for the purposes of a Special Meeting.

20. If within thirty minutes after the time fixed for holding the Meeting a quorum is not present, the Meeting shall be dissolved, and all matters which might, if a quorum had been present, have been done at a Meeting (other than a Special Meeting) so dissolved, may forthwith be done on behalf of the Meeting by the Council.

21. The President shall be Chairman at every Meeting, and in his absence one of the Vice-Presidents; and in the absence of all Vice-Presidents a Member of Council shall take the chair; and if

no Member of Council be present and willing to take the chair, the Meeting shall elect a Chairman.

22. The decision of a General Meeting shall be ascertained by show of hands, unless, after the show of hands, a poll is forthwith demanded, and by a poll when a poll is thus demanded. The manner of taking a show of hands or a poll shall be in the discretion of the Chairman, and an entry in the Minutes, signed by the Chairman, shall be sufficient evidence of the decision of the General Meeting. Each Member shall have one vote and no more. In case of equality of votes the Chairman shall have a second or casting vote: Provided that this Article shall not interfere with the provisions of the Bye-laws as to election by ballot.

23. The acceptance or rejection of votes by the Chairman shall be conclusive for the purpose of the decision of the matter in respect of which the votes are tendered: Provided that the Chairman may review his decision at the same Meeting if any error be then pointed out to him.

BYE-LAWS.

24. The Bye-laws set forth in the schedule to these Articles, and such altered and additional Bye-laws as shall be added or substituted as hereinafter mentioned, shall regulate all matters by the Articles left to be prescribed by the Bye-laws, and all matters which consistently with the Articles shall be made the subject of Bye-laws. Alterations in, and additions to, the Bye-laws, may be made only by resolution of the Members at an Annual General Meeting, after notice of the proposed alteration or addition announced at the previous Ordinary Meeting, and not otherwise.

COUNCIL.

25. The Council of the Institution shall be chosen from the Members only, and shall consist of one President, six Vice-Presidents, fifteen ordinary Members of Council, and of the Past-

Presidents; and the first Council (which shall include Past-Presidents of the existing Institution) shall be as follows:—

PRESIDENT.

John Robinson	Manchester.

PAST-PRESIDENTS.

Sir William G. Armstrong, C.B., D.C.L., LL.D., F.R.S.	Newcastle-on-Tyne.
Frederick J. Bramwell, F.R.S.	London.
Thomas Hawksley	London.
James Kennedy	Liverpool.
John Penn, F.R.S.	London.
John Ramsbottom	Manchester.
C. William Siemens, D.C.L., F.R.S.	London.
Sir Joseph Whitworth, Bart., D.C.L., LL.D., F.R.S.	Manchester.

VICE-PRESIDENTS.

I. Lowthian Bell, M.P., F.R.S.	Northallerton.
Charles Cochrane	Stourbridge.
Edward A. Cowper	London.
Charles P. Stewart	London.
Francis W. Webb	Crewe.
Percy G. B. Westmacott	Newcastle-on-Tyne.

COUNCIL.

Daniel Adamson	Manchester.
John Anderson, LL.D., F.R.S.E.	London.
Henry Bessemer	London.
Henry Chapman	London.
Edward Easton	London.
David Greig	Leeds.
Jeremiah Head	Middlesbrough.
Thomas R. Hetherington	Manchester.
Henry H. Laird	Birkenhead.
William Menelaus	Dowlais.
Arthur Paget	Loughborough.
John Penn, Jun.	London.
George B. Rennie	London.
William Richardson	Oldham.
John C. Wilson	Bristol.

26. The first Council shall continue in office till the Annual General Meeting in the year 1879. The President, two Vice-Presidents, and five Members of the Council (other than Past-Presidents), shall retire at each succeeding Annual General Meeting, but shall be eligible for re-election. The Vice-Presidents and Members of Council to retire each year shall, unless the Council agree amongst themselves, be chosen from those who have been longest in office, and in cases of equal seniority shall be determined by ballot.

27. The election of a President, Vice-Presidents, and Members of the Council, to supply the place of those retiring at the Annual General Meeting, shall be conducted in such manner as shall be prescribed by the Bye-laws from time to time in force, as provided by the Articles.

28. The Council may supply any casual vacancy in the Council (including any casual vacancy in the office of President) which shall occur between one Annual General Meeting and another, and the President or Members of the Council so appointed by the Council shall retire at the succeeding Annual General Meeting. Vacancies not filled up at any such Meeting shall be deemed to be casual vacancies within the meaning of this Article.

OFFICERS.

29. The Treasurer, Secretary, and other employés of the Institution shall be appointed and removed in the manner prescribed by the Bye-laws from time to time in force, as provided by the Articles. Subject to the express provisions of the Bye-laws the officers and servants of the Institution shall be appointed and removed by the Council.

30. The powers and duties of the officers of the Institution shall (subject to any express provision in the Bye-laws) be determined by the Council.

POWERS AND PROCEDURE OF COUNCIL.

31. The Council may regulate their own procedure, and delegate any of their powers and discretions to any one or more of their body, and may determine their own quorum: if no other number is prescribed, three Members of Council shall form a quorum.

32. The Council shall acquire the property of the existing Institution, and shall manage the property, proceedings, and affairs of the Institution, in accordance with the Bye-laws from time to time in force.

33. The Treasurer may, with the consent of the Council, invest in the name of the Institution any moneys not immediately required for the purposes of the Institution in or upon any of the following investments (that is to say):—

(A.) The Public Funds, or Government Stocks of the United Kingdom, or of any Foreign or Colonial Government guaranteed by the Government of the United Kingdom.

(B.) Real or Leasehold Securities, or in the purchase of real or leasehold properties in Great Britain or Ireland.

(C.) Debentures, Debenture Stock, or Guaranteed or Preference Stock, of any Company incorporated by special Act of Parliament, the ordinary Shareholders whereof shall at the time of such investment be in actual receipt of half-yearly or yearly dividends.

(D.) Stocks, Shares, Debentures, or Debenture Stock of any Railway, Canal, or other Company, the undertaking whereof is leased to any Railway Company at a fixed or fixed minimum rent.

(E.) Stocks, Shares, or Debentures of any East Indian Railway or other Company, which shall receive a contribution from Her Majesty's East Indian Government of a fixed annual percentage on their capital, or be guaranteed a fixed annual dividend by the same Government.

(F.) The security of rates levied by any corporate body empowered to borrow money on the security of rates, where such borrowing has been duly authorised by Act of Parliament.

34. The Council may, with the authority of a resolution of the Members in General Meeting, borrow moneys for the purposes of the Institution on the security of the property of the Institution.

35. No act done by the Council, whether *ultra vires* or not, which shall receive the express or implied sanction of the Members of the Institution in General Meeting, shall be afterwards impeached by any Member of the Institution on any ground whatsoever, but shall be deemed to be an act of the Institution.

NOTICES.

36. A notice may be served by the Council of the Institution upon any Member, Graduate, Associate, or Honorary Life Member, either personally or by sending it through the post in a prepaid letter addressed to such Member, Graduate, Associate, or Honorary Life Member, at his registered place of abode.

37. Any notice, if served by post, shall be deemed to have been served at the time when the letter containing the same would be delivered in the ordinary course of the post, and in proving such service it shall be sufficient to prove that the letter containing the notice was properly addressed and put into the post office.

38. No Member, Graduate, Associate, or Honorary Life Member, not having a registered address within the United Kingdom shall be entitled to any notice; and all proceedings may be had and taken without notice to such Member in the same manner as if he had had due notice.

Bye-laws.

(*Last Revision, January* 1885.)

MEMBERSHIP.

1. Members, Graduates, Associates, and Honorary Life Members of the existing Institution, may, upon signing and forwarding to the Secretary of the Institution a claim according to Form D in the Appendix, become Members, Graduates, Associates, or Honorary Life Members respectively of the Institution without election or payment of entrance fees.

2. Candidates for admission as Members must be Engineers not under twenty-four years of age, who may be considered by the Council to be qualified for election.

3. Candidates for admission as Graduates must be Engineers holding subordinate situations and not under eighteen years of age; and they may afterwards be admitted as Members at the discretion of the Council.

4. Candidates for admission as Associates must be gentlemen not under twenty-four years of age, who from their scientific attainments or position in society may be considered eligible by the Council.

5. The Council shall have the power to nominate as Honorary Life Members gentlemen of eminent scientific acquirements, who in their opinion are eligible for that position.

6. The Members, Graduates, Associates, and Honorary Life Members shall have notice of and the privilege to attend all Meetings, but Members only shall be entitled to vote thereat.

ENTRANCE FEES AND SUBSCRIPTIONS.

7. An Entrance Fee of £2 shall be paid by each Member, except Members of the existing Institution, who shall pay no Entrance Fee, and Graduates admitted as Members, who shall pay an Entrance Fee of £1. Each Member shall pay an Annual Subscription of £3.

8. An Entrance Fee of £1 shall be paid by each Graduate, except Graduates of the existing Institution, who shall pay no Entrance Fee. Each Graduate shall pay an Annual Subscription of £2.

9. An Entrance Fee of £2 shall be paid by each Associate, except Associates of the existing Institution, who shall pay no Entrance Fee. Each Associate shall pay an Annual Subscription of £3.

10. All Subscriptions shall be payable in advance, and shall become due on the 1st day of January in each year; and the first Subscription of Members, Graduates, and Associates, shall date from the 1st day of January in the year of their election.

ELECTION OF MEMBERS, GRADUATES, AND ASSOCIATES.

11. A recommendation for admission according to Form A in the Appendix shall be forwarded to the Secretary, and by him be laid before the next Meeting of the Council. The recommendation must be signed by not less than five Members if the application be for admission as a Member or Associate, and by three Members if it be for a Graduate.

12. All Elections shall take place by ballot, three-fifths of the votes given being necessary for election.

13. All applications for admission shall be communicated by the Secretary to the Council for their approval previous to being

inserted in the ballot list for election, and the approved ballot list shall be signed by the President and forwarded to the Members. The ballot list shall specify the name, occupation, and address of the Candidates, and also by whom proposed and seconded. The lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

14. The Elections shall take place at the General Meetings only.

15. When the proposed Candidate is elected, the Secretary shall give him notice thereof according to Form B; but his name shall not be added to the list of Members, Graduates, or Associates of the Institution until he shall have paid his Entrance Fee and first Annual Subscription, and signed the Form C in the Appendix.

16. In case of non-election, no mention thereof shall be made in the Minutes, nor any notice given to the unsuccessful Candidate.

17. A Graduate or Associate desirous of being transferred to the class of Members shall forward to the Secretary a recommendation according to Form E in the Appendix, signed by not less than five Members, which shall be laid before the next meeting of Council for their approval. On their approval being given, the Secretary shall notify the same to the Candidate according to Form F if an Associate, and according to Form G if a Graduate; but his name shall not be added to the list of Members until he shall have signed the Form H, and, if a Graduate, shall have paid £1 additional entrance fee, and £1 additional subscription for the current year.

ELECTION OF PRESIDENT, VICE-PRESIDENTS, AND MEMBERS OF COUNCIL.

18. Candidates shall be put in nomination at the General Meeting preceding the Annual General Meeting, when the Council are to present a list of their retiring Members who offer themselves for re-election; any Member shall then be entitled to add to the

list of Candidates. The ballot list of the proposed names shall be forwarded to the Members. The ballot lists shall be opened only in the presence of the Council on the day of election, by a Committee to be appointed for that purpose.

APPOINTMENT AND DUTIES OF OFFICERS.

19. The Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council.

20. The Secretary of the Institution shall be appointed as and when a vacancy occurs by the Members at a General or Special Meeting, and shall be removable by the Council upon six months' notice from any day. The Secretary shall give the same notice. The Secretary shall devote the whole of his time to the work of the Institution, and shall not engage in any other business or profession.

21. It shall be the duty of the Secretary, under the direction of the Council, to conduct the correspondence of the Institution; to attend all meetings of the Institution, and of the Council, and of Committees; to take minutes of the proceedings of such meetings; to read the minutes of the preceding meetings, and all communications that he may be ordered to read; to superintend the publication of such papers as the Council may direct; to have the charge of the library; to direct the collection of the subscriptions, and the preparation of the account of expenditure of the funds; and to present all accounts to the Council for inspection and approval. He shall also engage (subject to the approval of the Council) and be responsible for all persons employed under him, and set them their portions of work and duties. He shall conduct the ordinary business of the Institution, in accordance with the Articles and Bye-laws and the directions of the President and Council; and shall refer to the

President in any matters of difficulty or importance, requiring immediate decision.

MISCELLANEOUS.

22. All Papers shall be submitted to the Council for approval, and after their approval shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council.

23. All books, drawings, communications, &c., shall be accessible to the Members of the Institution at all reasonable times.

24. All communications to the Meetings shall be the property of the Institution, and be published only by the authority of the Council.

25. None of the property of the Institution—books, drawings, &c.—shall be taken out of the premises of the Institution without the consent of the Council.

26. All donations to the Institution shall be enumerated in the Annual Report of the Council presented to the Annual General Meeting.

27. The General Meetings shall be conducted as far as practicable in the following order :—

1st. The Chair to be taken at such hour as the Council may direct from time to time.

2nd. The Minutes of the previous Meeting to be read by the Secretary, and, after being approved as correct, to be signed by the Chairman.

3rd. The Ballot Lists, previously opened by the Council, to be presented to the Meeting, and the new Members, Graduates, and Associates elected to be announced.

4th. Papers approved by the Council to be read by the Secretary, or, with the consent of the Council, by the Author.

28. Each Member shall have the privilege of introducing one friend to any of the Meetings; but, during such portion of any meeting as may be devoted to any business connected with the management of the Institution, visitors shall be requested by the Chairman to withdraw, if any Member asks that this shall be done.

29. Every Member, Graduate, Associate, or Visitor, shall write his name and residence in a book to be kept for the purpose, on entering each Meeting.

30. The President shall ex officio be Member of all Committees of Council.

31. Seven clear days' notice at least shall be given of every meeting of the Council. Such notice shall specify generally the business to be transacted by the meeting. No business involving the expenditure of the funds of the Institution (except by way of payment of current salaries and accounts) shall be transacted at any Council meeting unless specified in the notice convening the meeting.

32. The Council shall present the yearly accounts to the Members at the Annual General Meeting, after being audited by a professional accountant, who shall be appointed annually by the Members at a General or a Special Meeting, at a remuneration to be then fixed by the Members.

33. In the case of Members, Associates, or Graduates, elected in the last three months of any year, the first subscription shall cover both the year of election and the succeeding year.

34. No Proceedings or Ballot Lists shall be sent to Members, Associates, or Graduates, who are in arrear with their subscriptions more than twelve months.

35. Any Member wishing to have a copy of the Papers sent to him for consideration beforehand can do so by sending in his name once in each year to the Secretary; and a copy of all Papers shall then be forwarded to him as early as possible prior to the date of the Meeting at which they are intended to be read.

36. At any Meeting of the Institution any Member shall be at liberty to re-open the discussion upon any Paper which has been read or discussed at the preceding Meeting; provided that he signifies his intention to the Secretary at least one month previously to the Meeting, and that the Council decide to include it in the notice of the Meeting as part of the business to be transacted.

APPENDIX.

FORM A.

Mr. being not under twenty-four years of age, and desirous of admission into the Institution of Mechanical Engineers, we the undersigned proposer and seconder from our personal knowledge, and we the three other signers from trustworthy information, propose and recommend him as a proper person to become a thereof.

Witness our hands, this day of

Members.

FORM B.

SIR,—I have to inform you that on the you were elected a of the Institution of Mechanical Engineers. In conformity with the rules, your election cannot be confirmed until the enclosed form be returned to me with your signature, and until your Entrance Fee and first Annual Subscription be paid, the amounts of which are and respectively. If these be not received within two months from the present date, the election will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM C.

I, the undersigned, being elected a of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they are now formed or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

FORM D.

As a of the Institution of Mechanical Engineers, I claim to become a of the Association incorporated under the same name.

Please register me as a

FORM E.

Mr. being of the required age, and desirous of being transferred into the class of Members of the Institution, we, the undersigned, from our personal knowledge, recommend him as a proper person to become Member of the Institution of Mechanical Engineers.

FORM F.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature. If this be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM G.

SIR,—I have to inform you that the Council have approved of your being transferred to the class of Members of the Institution of Mechanical Engineers. In conformity with the rules, your transference cannot be confirmed until the enclosed form be returned to me with your signature, and until your additional Entrance Fee (£1) and additional Annual Subscription (£1) be paid for the current year. If these be not received within two months from the present date, the transference will become void.

I am, Sir,

Your obedient servant,

Secretary.

FORM H.

I, the undersigned, having been transferred to the class of Members of the Institution of Mechanical Engineers, do hereby agree that I will be governed by the regulations of the said Institution, as they now exist, or as they may hereafter be altered; that I will advance the objects of the Institution as far as shall be in my power, and will attend the Meetings thereof as often as I conveniently can: provided that, whenever I shall signify in writing to the Secretary that I am desirous of withdrawing from the Institution, I shall (after the payment of any arrears which may be due by me at that period) be free from this obligation.

Witness my hand, this day of

Institution of Mechanical Engineers.

PROCEEDINGS.

February 1886.

The Thirty-ninth Annual General Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, the 4th of February 1886, at Half-past Seven o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a Committee of the Council, and that the following twenty-eight candidates were found to be duly elected:—

MEMBERS.

Thomas Alfred Adamson,	Southampton.
John Reid Chalmers,	London.
Robert Coles,	Coventry.
Robert Dixon,	Gateshead.
Dugald Drummond,	Glasgow.
Norman Duncan,	Rangoon.
Charles Williams Guy,	London.
John James Hanbury,	London.
John Hunter,	Leeds.
Thomas Jackson,	Leeds.
William Hamilton Martin,	Flushing.
Thomas Joseph Noakes,	London.
Frank Bailey Passmore,	Birmingham.
James Pollock,	London.

REGINALD ARTHUR SMITH, . . .	Manchester.
FREDERICK SEATON SNOWDON, . .	London.
GEORGE REYNOLDS TURNER, . .	Langley Mill.
TOM NEWSUM TURNER, ...	Langley Mill.
JOHN WILDRIDGE, ...	Sydney.
HENRI MICHEL WOLFF, ...	Llanrwst.

ASSOCIATE.

HARRY FISHER, ...	Sheffield.

GRADUATES.

ALBERT REUBEN ATKEY, . . .	Nottingham.
ANDREW BROWN, ...	London.
CHRISTIAN FREDERICK BUDENBERG, . .	London.
PERCY GRANT, ...	Ashford.
WILLIAM THEODORE LUCY, . . .	Oxford.
FRANK LLEWELLYN WARREN, . .	London.
JOSEPH A. WESLEY, ...	Lincoln.

The following Annual Report of the Council was then read:—

ANNUAL REPORT OF THE COUNCIL.

1886.

The Council of the Institution of Mechanical Engineers have great pleasure in presenting to the Members their thirty-ninth Annual Report.

The total number in all classes on the roll of the Institution at the end of last year was 1640, as compared with 1554 at the end of the previous year. The increase of 86 has arisen as follows:—there were added to the register during the year 134 names; there were lost from the register by deceases 20 names, and by resignation or removal 28 names.

The following Associate, and five Graduates, have been transferred by the Council in the course of the year to the class of Members:—

Joseph Ellershaw Pepper, . . .	Associate	. Leeds.
Samuel Richardson Blundstone, .	Graduate	. London.
Harry William Buddicom, . . .	do.	. Abergavenny.
William Henderson, ...	do.	. London.
Walter Saunders Paterson, . .	do.	. Rangoon.
Frank Walkinshaw, ...	do.	. Winchfield.

The following seventeen Deceases of Members of the Institution have occurred during the past year:—

Alan Charles Bagot, ...	London.
Peter Duckworth Bennett, ...	Tipton.
George Clark, Sen., ...	Sunderland.
John Holliday, ...	Westbromwich.
William Hoppe., ...	Moscow.
Thomas Horsley, ...	Derby.
Henry Charles Fleeming Jenkin, F.R.S., . . .	Edinburgh.
John Towlerton Leather (Associate), ...	Leeds.
Walter Macfarlane, ...	Glasgow.

Moraston Ormerod Norris (Graduate), ...	Hereford.
Thomas J. Perry, ...	Bilston.
Joseph D'Aguilar Samuda, ...	London.
Duncan Shaw, ...	Cordoba.
Isaac Slater, ...	Gloucester.
Henri Edouard Tresca (Honorary Life Member), .	Paris.
Albert Harrison Turner, ...	West Africa.
George Wilson, ...	Sheffield.

Among these the Council have deeply to deplore the recent loss, through a sad accident, of their colleague, Mr. Peter D. Bennett. His death has occurred in the interval between nomination and re-election as Member of Council. The vacancy thus occasioned will have to be dealt with by the new Council after the present Annual Meeting. M. Tresca was an Honorary Life Member of the Institution: apart from his fame as a distinguished pioneer in mechanical science, it will be remembered that he afforded active and valuable aid at the Meetings held in Paris in 1867 and 1878.

The following ten gentlemen have ceased to be Members of the Institution during the past year:—

Alfred Alexander, ...	King William's Town.
John Barber, ...	Leeds.
Raphael Martinez Campos, ...	Buenos Aires.
Samuel Chatwood, ...	Manchester.
Charles Simmons Church, ...	Barranquilla.
Joshua Field, ...	London.
James Jemson, ...	Preston.
John Rennie, ...	London.
Nanaji Narayan Waslekar (Associate), .	Calcutta.
David Maitland Yeomans, ...	New York.

In addition to these there have been eighteen Resignations of membership.

The Accounts for the year ending 31 December 1885 are now submitted to the Members (*see* Appendix I, pp. 8–11), after having been passed by the Finance Committee, and certified by Messrs. Robert A. McLean and Co., chartered accountants, the auditors to the Institution. It will be seen that the receipts during the year

were £5,330 11*s.* 0*d.*, while the expenditure was £4,004 2*s.* 11*d.*, leaving a balance of receipts over expenditure of £1,326 8*s.* 1*d.* A Balance Sheet, showing the financial position of the Institution at the end of the year, is appended. The total investments and other assets amount to £17,606 11*s.* 10*d.*; and the liabilities being *nil*, the same amount constitutes the capital of the Institution. The greater part thereof is invested in Railway Debenture Stocks, registered in the name of the Institution.

The Council desire to record their warmest thanks to Professor Kennedy for the very clear and able abstract which he has prepared of the Report of the Research Committee on Riveted Joints, and which includes the latest experiments. This abstract, together with the latest report, was presented to the Members at the Spring Meeting; and these, with the discussion upon them, have been circulated in the usual way. Further experiments, with thicker plates, larger rivets, and heavier pressures, have since been in progress under the continued direction of Professor Kennedy, and with the kind co-operation of Mr. Ralph H. Tweddell, the Landore Siemens-Steel Co., and Messrs. Fielding and Platt; and by the courtesy of the directors of Lloyd's Proving House at Netherton, the Committee on Riveted Joints have been able to arrange for the testing to be done at that establishment.

The Research upon Steel has been brought to a close: as the object sought—namely further knowledge in regard to the hardening, tempering, and annealing of steel—has been sufficiently realised for the present by the exhaustive investigations made under the superintendence of Sir Frederick Abel.

The Research Committee on Friction are arranging for a further series of experiments.

The additions to the Library of the Institution during the past year are enumerated in Appendix II, pp. 12–17. For these the Council desire to record their thanks to the several Donors. And in order to increase the value of the Library they invite continued donations of books, original pamphlets or reports, and particularly of records of practical experiments or researches.

The General Meetings in 1885 were the Annual General Meeting, an intermediate Meeting, and the Spring Meeting, all of which were held in London; the Summer Meeting held in Lincoln; and the Autumn Meeting held in Coventry. The Papers read and discussed at the seven sittings devoted to the purpose, and published in the Proceedings, were as follows:—

Final Report on Experiments bearing upon the question of the Condition in which Carbon exists in Steel; by Sir Frederick A. Abel, C.B., D.C.L., F.R.S.

Second Report of the Research Committee on Friction.

On recent improvements in Wood-Cutting Machinery; by Mr. George Richards.

Description of the Tower Spherical Engine; by Mr. R. Hammersley Heenan.

On the History of Paddle-Wheel Steam Navigation; by Mr. Henry Sandham.

Description of the Maxim Automatic Machine-Gun; by Mr. Hiram S. Maxim.

Report upon Experiments on Double-Riveted Lap and Butt Joints, Series XI, XII, XIII; by Professor Alexander B. W. Kennedy.

Abstract of Results of Experiments on Riveted Joints, with their applications to practical work; by Professor Alexander B. W. Kennedy.

Description of a Blooming Mill with Balanced Top Roll at the Ebbw Vale Works; by Mr. Calvert B. Holland.

Description of Dunbar and Ruston's Steam Navvy; by Mr. Joseph Ruston, M.P.

On recent adaptations of the Robey Semi-Portable Engine; by Mr. John Richardson.

On Private Installations of Electric Lighting; by Mr. Ralph H. C. Nevile.

On the Iron Industry of Frodingham; by Mr. George Dove.

Description of the Tripier Spherical Eccentric; by M. Louis Poillon.

On the Construction of modern Cycles; by Mr. Robert Edward Phillips.

The attendances at the Meetings were as follows:—at the Annual General Meeting 196 Members and 44 Visitors; at the intermediate Meeting in March 55 Members and 36 Visitors; at the Spring Meeting 84 Members and 79 Visitors; at the Summer Meeting 224 Members and 118 Visitors; and at the Autumn Meeting 48 Members and 85 Visitors.

For the Summer Meeting, held at Lincoln, a most comprehensive programme was prepared by the Members in the district. It included visits not merely to the engineering and manufacturing establishments in the city of Lincoln itself, but also to works at Grantham, Newark, Gainsborough, and Doncaster, to the docks at Grimsby, and to the blast-furnaces and iron-ore mines at Frodingham.

The Address with which the Meeting was opened by the President dealt with the relative advantages of iron and steel in the several branches of mechanical engineering. Mr. Ruston's steam navvy was described in detail in a paper rendered especially valuable by numerous practical results derived from actual working of the machine. An opportunity of visiting the ancient Cathedral under the most favourable circumstances was afforded by a special musical evening service, to which the Members were invited by the Dean and Chapter; and an appropriate Address delivered on the occasion by the Bishop has since, with his permission, been printed and circulated among the Members. A short description of the Frodingham iron industry, kindly contributed by Mr. Dove, proved an acceptable aid to the excursion to Frodingham, with which the week's Meeting was brought to a close.

In view of two interesting papers offered upon the manufacture of cycles, the Autumn Meeting was held in Coventry, the head-quarters of that industry. The Members attending the Meeting had the advantage of examining an extensive collection of modern cycles, including almost every type and specially brought together for the occasion by Mr. Phillips. The principal cycle and other works in the city were visited, including the extensive manufactory for producing watches on the interchangeable system.

Bearing in mind the cordial reception given to this Institution by the Belgians on the occasion of the Summer Meeting in 1883, the Council have invited the Association of Engineers from Liége University to hold their Annual Meeting for the present year in connection with the Summer Meeting of this Institution, and the invitation has been gladly accepted. The Summer Meeting will accordingly be held this year in London, as most convenient for the Belgian visitors, and will commence on Tuesday, the 17th of August.

In accordance with the Rules of the Institution, the President, three Vice-Presidents, and eight Members of Council, retire from office this day, under circumstances already explained fully. The result of the ballot for the election of the Council for the present year will be announced to the Meeting.

APPENDIX I.

Dr. ACCOUNT OF EXPENDITURE AND RECEIPTS

Expenditure.	£	s.	d.	£	s.	d.
To Printing and Engraving Proceedings of 1885	806	19	4			
„ Reprinting former Proceedings	22	9	0			
	829	8	4			
Less Authors' Copies of Papers, repaid	58	8	0	771	0	4
„ Printing General Index 1874–84				172	8	10
„ Stationery, Binding, and General Printing				223	16	11
„ Rent				550	0	0
„ Salaries and Wages				1,321	2	0
„ Coals, Firewood, and Gas				31	1	9
„ Fittings and Repairs				19	12	3
„ Postages				284	15	7
„ Insurance				5	2	3
„ Travelling Expenses				23	7	0
„ Petty Expenses				60	7	8
„ Meeting Expenses—						
Printing	208	17	9			
Reporting	55	0	10			
Diagrams, Screen, &c.	31	12	5			
Travelling and Incidental Expenses	140	0	11	435	11	11
„ Summer Dinner				76	2	11
„ Research				24	15	4
„ Books purchased				4	18	2
Total Expenditure in 1885				4,004	2	11
Balance, being excess of Receipts over Expenditure, carried down				1,326	8	1
				£5,330	11	0

To amount invested in £1325 Metropolitan Ry. 3½% Debenture Stock	1,350	2	11
Cash Balance at this date	1,830	10	6
	£3,180	13	5

APPENDIX I.

FOR THE YEAR ENDING 31st DECEMBER 1885. *Cr.*

Receipts.	£	s.	d.	£	s.	d.
By Entrance Fees—						
114 *New Members at* £2	228	0	0			
1 *New Associate at* £2	2	0	0			
22 *New Graduates at* £1	22	0	0			
5 *Graduates transferred to Members at* £1	5	0	0	257	0	0
„ Subscriptions for 1885—						
1325 *Members at* £3	3,975	0	0			
29 *Associates at* £3	87	0	0			
105 *Graduates at* £2	210	0	0			
5 *Graduates transferred to Members at* £1	5	0	0	4,277	0	0
„ Subscriptions in arrear—						
58 *Members at* £3	174	0	0			
1 *Graduate at* £2	2	0	0			
1 *Associate, instalment*	2	10	0	178	10	0
„ Subscriptions in advance—						
13 *Members at* £3	39	0	0			
2 *Graduates at* £2	4	0	0	43	0	0
„ Donation				1	0	0
„ Interest—						
From Investments	432	1	1			
From Bank	31	12	11	463	14	0
„ Reports of Proceedings—						
Extra Copies sold				110	7	0
				£5,330	11	0

By Balance brought down				1,326 8 1
Cash Balance 31st December 1884				1,854 5 4
				£3,180 13 5

Dr. BALANCE SHEET

	£	s.	d.
Capital of the Institution at this date	17,606	11	10

£17,606 11 10

(*Signed*) E. H. CARBUTT, M.P.
SIR JAMES N. DOUGLASS.
ALEXANDER B. W. KENNEDY.
JOSEPH TOMLINSON.
Finance Committee.

AS AT 31ST DECEMBER 1885. *Cr.*

	£	s.	d.	£	s.	d.
By Cash—*In Union Bank, on Deposit*	950	0	0			
„ „ „ *on Current account* . .	380	10	6			
In Imperial Bank	500	0	0	1,830	10	6
„ Investments—						
£ 3,178 *London & N. W. Ry. 4% Debenture Stock*						
2,200 *North Eastern* „ „ „ „						
2,466 *Midland* „ „ „ „						
1,800 *Great Western* „ „ „ „						
891 *Metropolitan* „ „ „ „						
1,325 „ „ 3½% „ „						
11,860 . . . . . *cost*				11,967	4	3
Note—The Market Value of these investments at 31st Dec. 1885 was about £14,000.						
„ Subscriptions in Arrear				389	0	0
„ Office Furniture and Fittings				350	0	0
„ Library and Proceedings				2,669	17	1
„ Drawings, Engravings, Models, Specimens, and Sculpture .				400	0	0
				£17,606	11	10

Audited and Certified by

ROBERT A. McLEAN & Co., Chartered Accountants,
1 Queen Victoria Street, London, E.C.

APPENDIX II.

LIST OF DONATIONS TO LIBRARY.

Justus Perthes' Taschen-Atlas; from Mr. Arthur Barclay.

Comparative Vocabularies of the Indian Tribes of British Columbia (with Map); from the Geological and Natural History Survey of Canada.

Descriptive sketch of the Physical Geography and Geology of the Dominion of Canada; from the Geological and Natural History Survey of Canada.

Annals of Lloyd's Register; from the Committee.

Engineering for Estates, by Alan Bagot; from the author.

Recent phases of the Sewage question, by Henry Robinson; from the author.

Pumping Machinery, by Erasmus D. Leavitt, Jun.; from the author.

Harbours and Docks, 2 vols., by L. F. Vernon-Harcourt; from the author.

Analysis of the principles of Economics, Part I, by Patrick Geddes; from the author.

Mechanical Refrigeration of Air and its applications, by T. B. Lightfoot; from the author.

River Pollution, by Henry Robinson; from the author.

Destruction of the English Dam, Sierra County, California, by Augustus J. Bowie, Jun.; from the author.

British Iron Trade Report, 1884; from Mr. J. S. Jeans.

Photographs of Electric Marine Governor and Isochronometers; from Mr. William W. Girdwood.

Board of Trade Reports on Boiler Explosions; from the Board of Trade.

Board of Trade Reports on Boiler Explosions, Nos. 46 to 86; from the Manchester Steam Users' Association.

Reports of the U.S. Chief of Ordnance; from the Ordnance Committee Office, Washington, U.S.

Traité théorique et pratique des Pompes et Machines à élever les Eaux, Vol. I (with Plates), by L. Poillon; from the author.

Transverse Strength of Timber, by Gaetano Lanza; from Mr. George A. Mower.

From Keel to Truck, a Marine Dictionary in English, French, and German, by Captain H. Paasch; from the author.

Vacuum Continuous Automatic Brake with universal coupling; from Mr. Alfred L. Sacré.

Board of Trade Review of Boiler Rules and Boiler Construction (Departmental Paper No. 100); from Mr. Thomas W. Traill.

Railway Safety Appliances; from Messrs. Saxby and Farmer.

Library Catalogue of University College, London (3 vols.); from the College.

Principes en usage dans les Ateliers de MM. Carels Frères, Gand; from the firm.

Report of the Chinese Imperial Maritime Customs, 1885; from the Inspector General, Chinese Customs Office.

Berly's universal Electrical Directory, 1885; from Messrs. William Dawson and Sons.

Adcock's Engineers' Pocket-Book for 1885; from the proprietor.

Études sur l'Étain dans l'antiquité, by Germain Bapst; from Mr. Henry Chapman.

Lower Thames Valley Main Sewerage, by Henry Robinson; from the author.

Draught of Carriages, by William Philipson; from the author.

Trinity House Report on Lighthouse Illuminants, Parts I and II; from Sir James N. Douglass.

Dun Echt Observatory publications, Vol. III, Mauritius Expedition 1874; from the Earl of Crawford and Balcarres.

Maurice's Fire-Damp Indicator, by Arthur H. Maurice; from the author.

Presidential Address to the Mechanical Science Section of the British Association, Aberdeen 1885, by Benjamin Baker; from the author.

Memoirs of the Tokio Daigaku, No. 11 (with Tables and Plates); from the President of the Tokio Daigaku.

Heat in its Mechanical Applications, Lectures at the Institution of Civil Engineers; from the Institution.

Centenary Review of the Asiatic Society of Bengal, 1784–1883; from the Society.

Katalog der Bibliothek der Königlichen Technischen Hochschule zu Berlin; from the School.

Price-Book of Machinery and Ironwork; from Messrs. Stothert and Pitt.

Ports Maritimes de la France (with Maps); from the Minister of Public Works.

The Interoceanic Problem and its scientific solution, by E. L. Corthell; from the author.

Theorie der Bremsen der Eisenbahnwagen, by Josef Bartl; from the author.

Notices (1868 et 1871) sur les Travaux scientifiques de M. Tresca; from M. Alfred Tresca.

Discours prononcés aux Funérailles de M. Tresca; from M. Alfred Tresca.

Manual of Metallurgy, Vol. I, by W. H. Greenwood; from the author.

Catalogue of Engines, Machinery, and Tools; from Messrs. Piercy and Co.

Modern Shipbuilding and the Men engaged in it, by David Pollock; from the author.

History of the Kew Observatory, by Robert H. Scott, F.R.S.; from the author.

Compound Locomotives (reprinted from "Engineering"); from Mr. Henry Chapman.

Guns of the ironclad "Riachuelo" and their alteration to the Armstrong system, by Lieutenant Duarte Huet de Bacellar Pinto Guedes; from Sir Joseph Whitworth, Bart.

Bicycles and Tricycles past and present, by Charles Spencer; from Mr. J. B. Dalzell.

Russian Railways, seventh conference of Rolling-Stock Engineers (with Drawings); from Mr. Thomas Urquhart.

Grazi-Tsaritsin Railway, Locomotive Running Rules, by Thomas Urquhart; from the author.

Grazi-Tsaritsin Railway, Petroleum Firing versus Anthracite; from Mr. Thomas Urquhart.

Grazi-Tsaritsin Railway, detailed Drawings of Eight-wheeled Goods Locomotive with tender; from Mr. Thomas Urquhart.

Address to the Society of Arts, by Sir Frederick Abel, Chairman of Council; from the author.

Irish Lexicography, by Robert Atkinson; from the Royal Irish Academy.

Theory and Practice of Hydro-Mechanics, Lectures at the Institution of Civil Engineers; from the Institution.

The Periodic Law, and the Relations among the Atomic Weights, by John A. R. Newlands; from the author.

Report on Machine-Tools and Wood-Working Machinery, by T. R. Hutton; from the Department of the Interior, Census Office, Washington, United States.

Illustrated Catalogue of Castings, 2 vols.; from Mr. Walter Macfarlane.

The following Publications from the respective Societies and Authorities:—

Reports of the Academy of Science, France.

Reports of the Royal Academy of Science, Belgium.

Reports of the Royal Institute of Engineers, Holland.

Engravings from the École des Ponts et Chaussées, Paris.

Annales des Ponts et Chaussées, Paris.

Proceedings of the French Institution of Civil Engineers.

Journal of the French Society for the Encouragement of National Industry.

Report of the French Association for the Advancement of Science.

Journal of the Marseilles Scientific and Industrial Society.

Annales de l'École Polytechnique de Delft.

Proceedings of the Engineers' and Architects' Society of Canton Vaud.

Proceedings of the Engineers' and Architects' Society of Austria.

Proceedings of the Architects' and Engineers' Society of Hanover.

Proceedings of the Engineers' and Architects' Society of Prague.

Proceedings of the Engineers' and Architects' Society of Rome.

Proceedings of the Engineers' and Architects' Society of Milan.

Proceedings of the Industrial Society of St. Quentin.

Proceedings of the Industrial Society of Mulhouse.

Proceedings of the Industrial Society of the North of France.
Proceedings of the German Society of Engineers.
Proceedings of the Swedish Society of Engineers.
Journal of the Norwegian Technical Society.
Journal of the Franklin Institute.
Transactions of the American Society of Civil Engineers.
Transactions of the American Society of Mechanical Engineers.
Transactions of the American Institute of Mining Engineers.
School of Mines Quarterly, Columbia College, New York.
Report of the Smithsonian Institution.
Report of the Master Car-Builders' Association, New York.
Proceedings of the American Railway Master-Mechanics' Association.
Proceedings of the United States Naval Institute.
Proceedings of the Massachusetts Institute of Technology; from Mr. George A. Mower.
Report of the United States Geological Survey.
United States Patent Office Gazette.
Professional Papers on Indian Engineering; from the Thomason College.
Proceedings and Journal of the Asiatic Society of Bengal.
Report of the Sassoon Mechanics' Institute, Bombay.
Proceedings of the Institution of Civil Engineers.
Journal of the Iron and Steel Institute.
Transactions of the Society of Engineers.
Journal of the Society of Telegraph-Engineers and Electricians.
Transactions of the Institution of Civil Engineers of Ireland.
Transactions of the North of England Institute of Mining and Mechanical Engineers.
Proceedings of the South Wales Institute of Engineers.
Transactions of the Institution of Engineers and Shipbuilders in Scotland.
Proceedings of the Chesterfield and Midland Counties Institute of Mining, Civil, and Mechanical Engineers.
Transactions of the Liverpool Engineering Society.
Transactions of the Midland Institute of Mining, Civil, and Mechanical Engineers.
Proceedings of the Cleveland Institution of Engineers.
Transactions of the West of Scotland Mining Institute.
Transactions of the North-East Coast Institution of Engineers and Shipbuilders.
Proceedings of the Royal Society of London.
Proceedings of the Royal Society of Edinburgh.
Proceedings of the Royal Institution.
Transactions of the Institution of Surveyors.
Journal of the Royal United Service Institution.

Professional Papers of the Royal Engineers Institute.
Proceedings of the Royal Artillery Institution.
Journal of the Royal Agricultural Society of England.
Journal of the Statistical Society.
Report of the British Association for the Advancement of Science.
Report of the Royal Cornwall Polytechnic Society.
Transactions of the Institution of Naval Architects.
Transactions of the Royal Institute of British Architects.
Transactions of the Gas Institute.
Proceedings of the Physical Society of London.
Proceedings of the Literary and Philosophical Society of Manchester.
Report of the Manchester Geological Society.
Journal of the Royal Scottish Society of Arts.
Proceedings of the Philosophical Society of Glasgow.
Transactions and Proceedings of the Royal Irish Academy.
Journal of the Liverpool Polytechnic Society.
Journal of the Society of Arts.
Journal of the Society of Chemical Industry.
Reports of the Manchester Steam Users' Association; from Mr. Lavington E. Fletcher.
Midland Steam Boiler Inspection and Assurance Company, Records of Boiler Explosions in 1884; from Mr. Edward B. Marten.
Report of the National Boiler Insurance Company; from Mr. Henry Hiller.
Report of the Engine, Boiler, and Employers' Liability Company; from Mr. Michael Longridge.
Report of the Manchester Association of Employers, Foremen, and Draughtsmen.
Catalogue of the Liverpool Free Public Library.

The following Periodicals from the respective Editors:—

Revue générale des Chemins de fer.
Revue Universelle des Mines.
Revue Industrielle.
Moniteur Industriel.
Portefeuille Économique des Machines.
Stahl und Eisen.
Der Civil-Ingenieur.
Glaser's Annalen.
Giornale del Genio Civile.
The Railroad Gazette.
The American Engineer.
The American Manufacturer.
The Sanitary Engineer.
The Engineering and Mining Journal.
The Engineer.
Engineering.
The Railway Engineer.
The Marine Engineer.
Sanitary Engineering.
The Foreman Engineer & Draughtsman
The Building and Engineering Times.
The Electrical Review.

The Electrical Engineer.
Iron.
The Iron and Coal Trades Review.
The Ironmonger.
Ryland's Iron Trade Circular.
The Mechanical World.
The Mining Journal.
The Colliery Guardian.
The Machinery Market.
The Builder.
The Contract Journal.
The Gas and Water Review.
The Plumber and Decorator.
The Steamship.
The Shipping World.
The Fireman.
The Illustrated Science Monthly.
Invention.
Phillips' Monthly Machinery Register.

The President thought the Members would agree with him that the year just passed had not been an idle one, and that during its course the Institution had done some good and valuable work. Although the Institution was not a commercial enterprise, the facts that their income had exceeded their expenditure by over £1300, and that they possessed a capital amounting to some £17,600, were gratifying, and were not altogether devoid of significance as regarded the future. He had great pleasure in moving the adoption of the Annual Report of the Council which had just been read.

The motion was unanimously agreed to.

The President announced that the Ballot Lists for the election of Officers had been opened by a committee of the Council, and that the following were found to be elected for the present year:—

PRESIDENT.

Jeremiah Head, ... Middlesbrough.

VICE-PRESIDENTS.

E. Hamer Carbutt, M.P., . . . London.
David Greig, ... Leeds.
Joseph Tomlinson, Jun., . . . London.

MEMBERS OF COUNCIL.

WILLIAM DENNY, F.R.S.E., . . .	Dumbarton.
BENJAMIN A. DOBSON, . . .	Bolton.
SIR JAMES N. DOUGLASS, . . .	London.
ALEXANDER B. W. KENNEDY, . .	London.
EDWARD B. MARTEN, ...	Stourbridge.
BENJAMIN WALKER, ...	Leeds.
J. HARTLEY WICKSTEED, . . .	Leeds.
THOMAS W. WORSDELL, . . .	Gateshead.

The decease of Mr. Peter D. Bennett, subsequently to his nomination at the last General Meeting for re-election as Member of Council, constituted a casual vacancy to be dealt with by the Council in accordance with No. 28 of the Articles of Association.

The vacancy has since been filled up by the appointment of Mr. EDWARD P. MARTIN, of Dowlais.

The Council for the present year will therefore be as follows:—

PRESIDENT.

JEREMIAH HEAD, ...	Middlesbrough.

PAST-PRESIDENTS.

SIR WILLIAM G. ARMSTRONG, C.B., D.C.L., LL.D., F.R.S., . . .	Newcastle-on-Tyne.
SIR LOWTHIAN BELL, BART., F.R.S., .	Northallerton.
SIR FREDERICK J. BRAMWELL, F.R.S., .	London.
THOMAS HAWKSLEY, F.R.S., . .	London.
JAMES KENNEDY, ...	Liverpool.
JOHN RAMSBOTTOM, ...	Alderley Edge.
JOHN ROBINSON, ...	Manchester.
PERCY G. B. WESTMACOTT, . .	Newcastle-on-Tyne.
SIR JOSEPH WHITWORTH, BART., D.C.L., LL.D., F.R.S., . . .	Manchester.

VICE-PRESIDENTS.

Daniel Adamson,	Manchester.
E. Hamer Carbutt, M.P.,	London.
Charles Cochrane,	Stourbridge.
David Greig,	Leeds.
Richard Peacock, M.P.,	Manchester.
Joseph Tomlinson, Jun.,	London.

MEMBERS OF COUNCIL.

William Denny, F.R.S.E.,	Dumbarton.
Benjamin A. Dobson,	Bolton.
Sir James N. Douglass,	London.
Samuel W. Johnson,	Derby.
Alexander B. W. Kennedy,	London.
Edward B. Marten,	Stourbridge.
Edward P. Martin,	Dowlais.
Arthur Paget,	Loughborough.
R. Price-Williams,	London.
Sir James Ramsden,	Barrow-in-Furness.
E. Windsor Richards,	Middlesbrough.
T. Hurry Riches,	Cardiff.
Benjamin Walker,	Leeds.
J. Hartley Wicksteed,	Leeds.
Thomas W. Worsdell,	Gateshead.

The President thanked the Members for the honor they had done him in electing him as their President for another year. If any success had been attained during the past year, and if the affairs of the Institution had been conducted to the satisfaction of the Members, their thanks were due to the Members of Council who had so ably assisted him throughout the year. He was happy to state—although it was hardly necessary for him to do so, because the Members must themselves have observed the fact already—that the Council had worked throughout the year in the most harmonious way; and to the best of his knowledge and belief

(The President.)

the Institution was progressing in the most satisfactory manner. The Members had now elected almost the same Council for the ensuing year; and he had not the slightest doubt that the Institution would do as well or better in the future than it had done in the past. The only drawback to the complete satisfaction with which he would otherwise have been able to review the course of last year was the loss the Council had sustained by the death of their late colleague, Mr. Peter D. Bennett. He need hardly say this event had been a great grief to the Council, and one which they would not soon forget.

The PRESIDENT said that a year ago a resolution had been passed by the Members to the effect that in future they would themselves year by year appoint an auditor for the Institution accounts. It was now their duty to appoint an auditor for the present year.

On the motion of Mr. JOHN G. MAIR, seconded by Mr. HENRY CHAPMAN, it was unanimously resolved that Mr. Robert A. McLean, chartered accountant, 1 Queen Victoria Street, London, be re-appointed to audit the accounts of the Institution for the present year, at a remuneration of Ten Guineas, being the same as heretofore.

Mr. M. POWIS BALE proposed the following motion for an alteration in Bye-Law No. 22, of which he had given notice at the last General Meeting, the proposed alteration being shown in italics:—

That Bye-Law No. 22 be amended to read as follows:—"All Papers shall be submitted to the Council for their approval, and after their approval *shall be printed and circulated among the Members at least one week before the General Meetings; and an Abstract only of each Paper* shall be read by the Secretary at the General Meetings, or by the Author with the consent of the Council."

As the Institution met only four or five times a year, and therefore the time at its disposal was limited, it appeared to him that a certain amount of time was apt to be wasted when very long papers were read in detail. It might be supposed that the object of the motion was to allow intending speakers to consult authorities

during the week before the meeting, during which they would have the papers. That was not the object; but even were it so, it might prevent hazy statements of facts in the discussions. He was aware of the difficulty of getting papers from practical engineers. Some had no objection to give their opinions and ideas in discussion, but could not spare the time to write a paper. Supposing the supply of papers to fail, he thought a hint might be taken from kindred societies, such as the American Society of Mechanical Engineers, where engineering subjects were introduced for discussion, which might not rise to the dignity of a paper; and the result was that valuable information was thereby obtained which was published in their proceedings. It would be observed that their own Proceedings just published of the last Meeting contained only a single paper, which result he thought was hardly commensurate with the importance of the Institution. The object of his motion was simply to give more time for discussion. In several societies whose meetings he occasionally attended it was true he had noticed that certain members spoke on all possible subjects and on all possible occasions, the result being that the discussions had often to be prematurely closed, and many practical men had not an opportunity of stating their views. Such a result however he deprecated in connection with the motion he had proposed, the object of which he trusted was now sufficiently apparent.

Mr. A. J. Wallis Tayler seconded the motion.

The President pointed out that the effect of the motion would be to compel the circulation of all papers a week before the meeting, and to prohibit the Council from having any paper read in full. It would also oblige the Council to have abstracts made of every paper. As therefore the alteration was one which affected the carrying on of the business of the Institution with regard to the meetings, it concerned mainly the Council and their officers. Accordingly, while it was within the power of the Members to carry the motion or not as they pleased, the Council had thought that the Members would probably desire, before proceeding further

(The President.)

with the discussion of the motion, to hear whether the Council had considered it, and what view they took of it. In that expectation the Council had prepared a statement of their opinions upon the subject after a thorough discussion; and in accordance with the wish of the Members, as signified by their applause, he would now direct the reading of the statement.

The following statement was accordingly read:—

The existing Bye-law simply directs that all Papers approved by the Council "*shall be read*" at the General Meetings, without defining that the reading shall be either in extenso or in abstract. The alteration would restrict the reading to "*an Abstract only*" of each paper; and would thus preclude the possibility of reading in extenso any paper, however important.

The Council have hitherto judged every paper upon its merits, and have already given effect to Mr. Bale's intention in numerous cases: among which may be instanced the historical paper on Paddle-Wheel Navigation, read in abstract in twenty-five minutes at the last Spring Meeting, when the reading in extenso would have occupied one hour and twenty-five minutes. On the other hand the descriptions of the Maxim Machine-Gun and the Ruston Steam Navvy are examples of papers which were recommended to be read in extenso, with the exception only of a slight condensation of statistical statements; and the same was the case at the last Meeting with the paper on the Construction of Cycles, which could not have been read more in abstract than it was, without marring the interest of the accompanying exhibition of cycles specially brought together by the author for illustrating his paper.

The enforced preparation of an Abstract would entail an increase of labour, either upon the author or upon the Institution, which can be more advantageously devoted to increasing the value of the paper itself. The difficulty would be to prepare an Abstract satisfactory both to the author and to the meeting. Many an author might object to offer a paper which should have to undergo such treatment, or might neglect to furnish a suitable abstract himself.

Advance Proofs of the papers are already issued to the Council and to all Members applying for them, as well as to a large number of Members and visitors who do not apply, but are specially invited to attend the meetings and take part in the discussions. The proposed alteration would involve an issue eight or ten times greater than at present of such advanced proofs: the extra cost of which, estimated on the basis of the last year's experience, would amount to more than £160 a year. This is exclusive of the largely increased demand upon the time and labour of the staff, which would probably add another £100 a year to the office expenses.

The issue of Advance Proofs is made as long before the meetings as possible, generally more than a week beforehand. But it occasionally happens, as it did at the last meeting, that it is impracticable, even with the utmost exertions, to ensure its taking place a clear week before the meeting; and the difficulty would be proportionately increased if the issue were made to the whole of the Members.

Mr. Henry Robinson said he did not know whether the mover of the resolution proposed that copies of the diagrams on a reduced scale should be issued with the abstracts of the papers; because otherwise many of the papers could with difficulty be understood. This appeared to him to be a point that had been overlooked by the Council in their admirable summary of the case. It seemed to him that, in the case of many of the papers, diagrams were absolutely essential for their proper appreciation. Without the opportunity of studying the diagrams many engineers would be unable to take part in the discussion, even though the printed paper were already in their hands. For these reasons he thought the proposed amendment of the existing bye-law was not a desirable one to be carried out; and he therefore simply moved that the proposal be negatived.

Mr. Charles Cochrane said he had been anticipated in the observation he had intended to make in regard to the diagrams, which in the majority of cases were vital to the understanding of the papers. It was of course utterly impracticable to supplement the papers with diagrams to be issued to all the Members a week before the meetings. He had therefore much pleasure in seconding the direct negative moved by Mr. Robinson.

The practice of the North of England Institute of Mining Engineers was to send out a brief statement of the purport of the papers, so as to direct attention to them. The members were thus led to think about the subjects, and to desire to be present at the discussion upon the different papers, from knowing their scope beforehand. Such a statement need amount to no more than a few lines, just enough to indicate the general leading features of the subjects to be brought before the meetings.

Mr. J. ALFRED GRIFFITHS suggested issuing to the whole of the Members about as much in the way of an abstract of the papers as was given in the index of the Proceedings, instead of supplying the complete papers to a few only of the Members.

Mr. HENRY ROBINSON pointed out that any of the Members could now get the whole of each paper beforehand, if they desired.

Mr. ARTHUR PAGET said it was fully within the power of the Council to accept and carry into effect the suggestion made by Mr. Griffiths, without any resolution upon it. In certain cases he could readily see it might be advisable to adopt that method; but taking the list of papers for the present meeting, for example, he did not suppose it would be considered requisite to give any abstract of the first paper, "Description of an Autographic Test-Recording Apparatus," the title of which was sufficiently self-explanatory. With regard to the next, "Description of Tensile Tests of Iron and Steel Bars," the title was tolerably self-explanatory; but in the light of Mr. Griffiths' remarks it might be desirable to amplify it a little more.

Mr. DAVID GREIG agreed that it was of importance, and would tend to more profitable discussions, if some brief account of the papers to be read were distributed to the Members. He was of opinion that such a course might bring Members to the meetings, and lead them to take more interest in the papers than they did at present. As to sending diagrams beforehand to all the Members of the Institution, he did not see how that could be done, because sometimes the diagrams were not ready till the day when the paper was to be read, much less a week beforehand. He thought however that giving the Members a little insight into the papers to be read might lead to some profitable result; and the suggestion of Mr. Cochrane and Mr. Griffiths was well worthy of consideration.

The PRESIDENT said the only issue before the Meeting was, strictly speaking, whether or not a certain definite alteration should

be made in a particular bye-law. The discussion which had taken place was by no means an unprofitable one; and he was sure the Council would take into consideration all they had heard. He quite agreed with Mr. Paget that the Council had already full power to make any of the suggested arrangements; and he was sure they had no other desire than to render the Institution as useful as possible to the Members.

The motion for the proposed alteration in Bye-Law 22 was then put to the Meeting, and negatived.

The following Papers were read, and on the proposal of the President were discussed together:—

Description of an Autographic Test-Recording Apparatus; by Mr. J. Hartley Wicksteed, of Leeds.

Description of Tensile Tests of Iron and Steel Bars; by the late Mr. Peter D. Bennett, of Tipton.

At Ten o'clock the Meeting was adjourned till the following evening. The attendance was 107 Members and 66 Visitors.

The Adjourned Meeting of the Institution was held at the Institution of Civil Engineers, London, on Friday, the 5th of February 1886, at Half-past Seven o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The adjourned discussion upon the two Papers read on the previous evening was resumed and completed.

The following Paper was then read and discussed:—

Description of a Hydraulic Buffer-Stop for Railways; by Mr. ALFRED A. LANGLEY, of Derby.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms for the Meeting of this Institution.

The Meeting then terminated. The attendance was 83 Members and 82 Visitors.

DESCRIPTION OF AN AUTOGRAPHIC TEST-RECORDING APPARATUS.

By Mr. J. HARTLEY WICKSTEED, of Leeds.

In the discussion arising from the writer's paper at the summer meeting of this Institution at Leeds in 1882 (Proceedings, page 384), on a Single-Lever Testing Machine for testing the strength of iron and steel under statical loads, it was urged by Mr. Druitt Halpin that there was wanted a permanent record of all that was going on in the sample during the process of destruction. Referring to a machine he had seen, to which there was a diagram-recording apparatus attached, he mentioned (p. 401) that "the sample was put in, and torn; and a complete diagram was obtained of the work done in getting the extension at every point, showing also the limit of elasticity, the breaking load, and the whole behaviour of the sample right through the process." The writer replied (p. 407) that, "with regard to the diagram-recording apparatus, he hoped there would be an opportunity of hearing more about it. It was a thing that was much wanted, and he had no doubt it would be as applicable to one testing machine as to another. In the meantime the ordinary method of taking successive observations with dividers and calipers, and plotting the results upon a card, was extremely reliable, and could be carried out with microscopic accuracy." Through the courtesy of Mr. Halpin the writer subsequently became thoroughly acquainted with the arrangement of the machine alluded to; but he found not only that the apparatus was unsuited for use with any other type of machine than the one it was made for, but also that that type of machine was in his opinion a faulty one, both from the large angle through which its knife-edges had to vibrate, and also from the vertical motion imparted to its poise-weight, which he considered would introduce unrecorded stresses on the sample of very considerable moment.

The attention of the writer had also been called to the subject of test diagrams by a paper "on certain physical tests and properties of mild steel" contributed to the Iron and Steel Institute in May 1882 (Journal, page 11) by Mr. Edward Richards of the Barrow Hæmatite Steel Works. In that paper the diagrammatic method was employed most effectively; but the diagrams had been plotted by hand, a most laborious process: in some instances the stress and extension were observed forty times during the progress of one test (page 12). It is clear that such observations require great skill and patience; but beyond the saving of time and labour there is also a further gain in obtaining the diagrams autographically, namely that the progress of the test is continuous without interruption from start to finish; and as time is a factor in the behaviour of a test piece, it is important in making tests for comparison that there should be no irregularity in this factor. In the present paper the word "strain" will be used for the extension or deformation of the specimen, and not for the load or stress.

Autograph Diagram. — The Autographic Test-Recording Apparatus to be described in the present paper is applicable to any testing machine where fluid pressure is employed; and it is so sensitive as even to register any stresses casually induced upon a sample by irregular manipulation of the machine, which would otherwise pass unrecorded. An enlarged copy of a self-recorded diagram produced by this apparatus is shown $1\frac{1}{2}$ times full size in Fig. 8, Plate 4, which may be taken as a typical record for mild steel or for best wrought-iron, these materials resembling each other very closely in their characteristic behaviour. Following the trace of the pencil it will be seen how the sample writes its autobiography: recording the tension put upon its fibres, and how it endured that stress, first with unyielding elasticity, next with notable extension till its climax of resistance was reached, and then with local deformation and diminishing resistance till it was broken.

Beginning at the point A, the trace ascends to 5, 10, and 15 tons tension; and in doing so it departs gradually from the vertical datum line by about $1\frac{1}{2}$-hundredths of an inch, or $1\frac{1}{2}$-thousandths of

the 10 inches length under tension; the amount of this departure or horizontal movement of the trace is the record of the specimen's extension, and it may be broadly stated that the whole of this gradual extension is elastic. With a little higher tension, at about 16½ tons, a sudden horizontal departure takes place at B, showing that with this degree of tension the sample has yielded to the extent of about one-fiftieth of its length. At this particular tension therefore of 16½ tons it is at once seen that the first unmistakable strain has taken place, and in comparison with this at no previous load. For the extension per ton of load had previously been only about 1-10,000th of the length; but at this point the sample suddenly extended 1-50th of its length, or 200 times as much, within the range of a single added ton of stress. Refined experiments may show that before this tension was reached, and during the elastic period, some minute permanent set may have taken place, and the questions may be debated of the point at which Hooke's law of perfect elasticity ceased to operate, and why; but with this graphic record traced by the specimen itself there can be no question as to where it first yielded palpably and unmistakably to the tension, and suffered substantial deformation. For all structural purposes this may be considered the yielding point; and a reasonable factor of safety within this point is more to the purpose than an arbitrary factor within the point of maximum load, which climax of resistance by following the trace is found at C at 24 tons, after the piece has extended about 20 per cent. Following the trace yet further, a record is found of rapidly diminishing resistance on the part of the sample, together with further extension; until it finally snaps at F at 20 tons of load, having undergone a total extension of 25 per cent. of its length. This completes the self-recorded testimony of the sample. To the deductions that can be drawn from it allusion will be made after the mechanism has been described by which the record is effected, and after a general explanation has been given of the whole system of testing adopted.

Record of Load. — In Fig. 1, Plate 1, is shown one of the Single-Lever Testing Machines in conjunction with the Autographic

Indicator. The sample S is held between an upper gripping box A and a lower gripping box B, shown to a larger scale in Figs. 5 and 6, Plate 3. The upper box is suspended from the back centre of a steelyard L, which by the adjustment of its poise-weight W weighs whatever pull is put upon the sample. The lower box is connected with a hydraulic cylinder F, shown in section in Fig. 7, Plate 3, which puts the pull upon the sample, and extends it until it breaks. Thus while the hydraulic cylinder is doing the mechanical work of breaking the sample, the steelyard is measuring the load that it sustains. The object of the indicator, shown to a larger scale in Figs. 2 to 4, Plates 1 and 2, is to record simultaneously the amount of the load and the extension due to that load. To get this simultaneous record the horizontal ram R of the indicator, which carries the pencil P, is in fluid connection with the hydraulic cylinder F, which puts the load upon the sample; and the indicator therefore partakes of that load. Round the outer end of the ram is coiled a spiral spring C, 15 inches long, as shown in Fig. 3, capable of closing 5 inches with a load of about 21 cwts. As the fluid pressure on the ram increases, the spring C becomes compressed; and as the fluid pressure on the ram decreases, the spring expands; the pencil P records the point of equilibrium between the two. The area of the ram R is about 1 square inch; and the fluid pressure, when the machine is exerting its full pull of 50 tons, rises to about 1·05 ton per square inch. The effective area of the piston in the main hydraulic cylinder F is 50 square inches; and with the pressure of 1·05 ton per square inch there is consequently a total pressure of 52½ tons on the piston, though it has to effect a pull of only 50 tons upon the sample. The margin of 2½ tons is rendered necessary by the friction of the hydraulic leathers which surround the piston and piston-rod, Fig. 7. Thus the water pressure is greater by the friction of the leathers than what would be due solely to the net load borne by the sample; and the indicator ram is subject to the gross pressure. This gross pressure however bears a constant proportion to the net load upon the sample; and the scale of the recorded diagram, Fig. 8, is constructed, not from any calculation of areas under pressure, but by noting the net tension which is passed through the sample, as

measured by the steelyard. The steelyard accordingly creates the vertical scale of load by which the diagram is valued; and the value in tons of the total height of the diagram is checked by poising the steelyard at the time the maximum resistance is reached, and thus assigning to the diagram an indication of the veritable weight supported by the sample. The subsidiary readings of the diagram are taken from the scale so constructed.

The friction of the hydraulic leathers appears to increase in regular proportion with each additional ton of pressure within the cylinder; and after correct deduction has been made of the initial friction which is offered by the leathers to any movement, then the scale is found to be perfectly uniform from 1 ton up to 50 tons load. This has been proved by putting a rigid specimen into the testing machine, adjusting the poise to 1 ton, then putting on the water pressure till the steelyard lifts, and letting the pencil of the indicator mark the card in that position for the first ton. Proceeding, the water pressure is slacked till the lever drops, the poise is adjusted to 2 tons on the steelyard, the hydraulic cylinder is again made to lift it, and the pencil records its position by a second mark. This is repeated through the whole range of the indicator, and no enlargement or contraction of scale or any other irregularity can be measured on the card between the first and last markings of the pencil. The zero line however of this scale must be made at that degree of water pressure which balances the initial resistance before mentioned, and check nuts on the indicator ram are adjusted so as never to allow the spring to press it below this line; thus the initial pressure of the spring balances the initial resistance of the leathers. In the indicator, as in the testing machine proper, the hydraulic pressure is doing the mechanical work of moving the pencil, while the steelyard is measuring the load of which that movement is the indication.

Besides the friction upon the leathers of the main cylinder, there remains to be considered also the friction upon the leather of the indicator-ram itself, which for simplicity has thus far been omitted from consideration. Now assuming that this friction is a steadily increasing quantity, as in the large cylinder, and assuming that the

indicator-ram were always moving in one direction, as the piston in the larger cylinder is, and at a uniform speed throughout the whole test, then the friction on the indicator-ram might be similarly disregarded, by merely constructing a scale which should make allowance for it—the loss by friction being the difference between the water pressure upon the ram in one direction and the nearly counterbalancing pressure of the indicator spring in the other. Supposing, as is the case, that this frictional loss amounts to one-sixth of the whole pressure, then a pressure of 24 cwts. on the indicator-ram would produce a compression in the spring of only 20 cwts.; and if the matter ended there, an indicator scale credited with one-fifth more than the scale of the spring would answer the purpose. But the case of the indicator is not the same as that of the hydraulic pulling cylinder. In the hydraulic pulling cylinder the motion is always in one direction; but the indicator must be free not only to advance when the water pressure increases, but also to recede when it diminishes. Between the water pressure and the spring pressure there must therefore be no difference caused by friction; for if there were, the water pressure might decline from 24 cwts. down to 20 cwts. before there was equilibrium of pressure in the water and in the spring; and it would have to decline further to about $16\frac{2}{3}$ cwts. before the excess of pressure in the spring would overcome the friction of the leather, and cause the pencil to travel back in response.

Freedom from Friction.—A means has accordingly been introduced into this indicator, by which the ram is set free from the impeding friction, and is thereby enabled to travel to and fro in response to the least possible difference of pressure between the water and the spring. This end is attained by the indicator-ram being made to revolve by belt power and by gearing, Figs. 3 and 4, Plate 2. The driving power being applied in a plane at right angles to the longitudinal travel of the ram, has no effect upon that travel; but it entirely overcomes the obstruction which the friction of the leather would otherwise offer to the free travel of the ram. The reality of the friction can be gathered from the fact that a belt is required 3 inches wide on pulleys 9 inches diameter and making 120

revolutions per minute, with a purchase of two to one in the gearing, transmitting about 1 HP., to overcome the friction; but being overcome circumferentially it disappears longitudinally, and the ram becomes sensitive enough to respond to the very smallest want of balance between the opposite forces of the water pressure and the spring. In actual practice a diagram is one-fifth higher, when taken with the ram revolving, than when the ram is not revolving; and with the ram revolving a record is obtained of any decrease in pressure, however slight, whereas a stationary ram needs a diminution amounting to nearly two-sixths of the whole load, or twice the friction of the leather, before the indicator records it.

Record of Extension.—For recording the extension of the sample simultaneously with the load upon it, the metallic paper on which the pencil travels is mounted on a brass barrel D, Figs. 3 and 4, Plate 2, like that of an ordinary steam indicator; and in accordance with the extension of the sample this barrel is made to revolve by means of the following arrangement. Two light clips JJ, Figs. 5 and 6, are clamped to the sample on the datum lines between which the extension is to be measured. A fine wire with a weight at its end rests upon the lower clip, and is thence led round a pulley on the upper clip; thence it goes horizontally along a radius bar G, Fig. 1, through a slot in the upright casting of the testing machine proper; and passing round a second equal pulley at the joint of the horizontal and vertical radius-bars G and H, it descends to coil round the barrel D carrying the paper, which is counterweighted so as to keep the wire taut. If however it were allowed to descend direct from the second pulley to the barrel, it would happen that, should the sample sway to and fro or rise and fall bodily, so that the angle contained between the two radius-bars themselves, or the angles contained between the radius-bars and the vertical ends of the wire, became smaller or larger, the wire in passing round those changed angles would become shortened or lengthened by the amount of angular alteration measured on the circumference of the pulleys round which it passes at the joints. The wire would thus

impart to the diagram barrel a movement which would not be due to any extension of the sample between the clips, but merely to a general movement of the whole bodily. To obviate this source of error a third equal pulley is introduced at the lower joint of the vertical radius-bar H, and the wire is led over it to the barrel; and the variation in the arc which the wire covers on this third pulley compensates exactly for the variation in the arcs of the first and second pulleys through the change of angles made by the radius-bars as the sample sways to and fro or moves bodily up and down. In other words, the wire begins with a plumb line ascending from where it rests upon the lower clip J up to the first pulley, and ends with a plumb line where it descends a few inches from the third pulley at the foot of the vertical radius-bar H down to the indicator barrel round which it coils; moreover between these two plumb lines the three pulleys round which the wire passes are of equal diameter; hence the three arcs which the wire covers on their circumferences at any moment must together add up always to half the circumference of one of them, though the proportion borne by the several pulleys may vary as the angles of the radius-bars change. The extent of this variation is quite immaterial, so long as it all takes place within the 180° included between the upward and downward plumb lines of the wire. Hence despite any general movement whatever of the sample, no rotation takes place of the indicator barrel except in response to an alteration in the distance between the clips clamped upon the sample.

A ruder apparatus would sufficiently well convey the total elongation of a sample, as required for general commercial purposes; but it requires all the refinement of this apparatus in order not to lose the record of the minute extensions that take place during the elastic period. Similarly a water-pressure indicator without the freedom from friction previously described might answer the purpose of recording by an ascertained scale the load at the time of first notable set, and also the maximum load carried; but it would not record the subsequent diminishing load during the local elongation, nor the load at the moment of fracture; nor would it record, as this indicator does, that curious phenomenon of fluctuating tenacity in

the sample just after the elastic period is passed and when the first important set takes place.

The moment the sample snaps, the indicator-ram being relieved from hydraulic pressure is shot back suddenly by the spring. By a simple contrivance this sudden return of the ram is made to lift the pencil clear of the paper, so that the record stops simultaneously with the cessation of stress at the moment of rupture.

Interpretation of Records.—A test sample being enabled by these mechanical means to record its own history in the form of a diagram, a few observations may be added as to the significance of that history and the inferences to be deduced from it.

Firstly, by measuring the area of the diagram, Fig. 8, Plate 4, the mechanical work expended throughout the stretching and breaking of the sample, over the portion that lies between the two clips or datum points, is readily obtained; and this figure appears to the writer to embody that value of metal so strongly insisted on by Sir Joseph Whitworth at the Manchester meeting of this Institution in 1875, where he said (Proceedings, page 290) that "the great value of a metal lay in its tensile strength and ductility combined. . . . In the case of the metal having a tensile strength of 40 tons per square inch and 30 per cent. of ductility, these two figures together amounted to a total of 70; and it was a great achievement to get so high a total divided in such nearly equal amounts between the two qualities of tensile strength and ductility." From this quotation it will be seen that it was then proposed to add together the figures which represented the strength in tons per square inch and the ductility in percentage of extension, and to take the sum of these two as a basis for making a comparison between the gross mechanical values of two metals.

Pursuing this idea of taking into account both the tensile resistance and the ductility of a material, the value will be found to be best expressed by the mechanical work required to produce rupture. This is given by the area of the diagram, and may be conveniently expressed in inch-tons, being the number of tons lifted one inch high which would represent the same work as has been

expended in breaking the sample. Though this suggestion may be by no means a new one, yet with a diagram quickly and cheaply made it becomes more easy to carry out in practice, and is therefore worth fresh attention.

Secondly, after the point of first palpable yielding in the sample at B, Fig. 8, the next most critical period is when its power to sustain the load begins to decline, which is shown by the descending line from C to F in the concluding portion of the diagram. After the climax of resistance has been reached at C, time alone would break the material without further increase of load; and as soon as the period of diminishing resistance has become established, it follows that the strains become localised till the sample is broken. The extension shown in the diagram from the climax at C to the point of fracture at F took place within only a small portion of the length of the sample, near to the place of its fracture. In other words, up to the climax C the extension was general throughout the length of the sample; but beyond that point the general extension ceased, the sample determined where it was about to break, the flow of the material became localised, and the contraction of area became very rapid at that part. If the test is conducted at a speed just not fast enough to produce any sensible heating of the sample during its general extension, the writer has observed that a local heating may be detected just as soon as the resistance of the sample begins to diminish, and even before the local contraction is perceptible to the touch. The heating is an indication that the flow of material, which had previously been going on slowly over the whole length of the sample, has at this stage become more rapid over a short portion; and the further proof of this is the perceptible local contraction which very speedily follows.

The loss of power to sustain the maximum load, occurring as it does concurrently with the localisation of the flow and with the local contraction of area, enables the point on the diagram to be marked at which local extension began. The importance of being able to mark this point is very great, because—whereas the general extension of the sample up to that point depends wholly on the quality of the material—the amount of the subsequent local extension

up to fracture depends very largely upon the shape of the sample. It will therefore be seen that by cutting off this later portion of the diagram from the earlier, and stating the earlier or general extension in percentage of the length of the sample, a just comparison as to ductility of material may be made between experiments tried on samples that were not of identical shape or proportions. In illustration, suppose two samples be taken of the same material, each 10 inches long, one $\frac{1}{2}$ inch diameter and the other 1 inch diameter, and both of them stretching 20 per cent. up to the climax C, Fig. 8; afterwards the $\frac{1}{2}$-inch sample during its local contraction of area will contribute say 2 per cent. more to the total extension, while the 1-inch sample will contribute about 5 per cent., raising the total extension to say 25 per cent., against the 22 per cent. total of the other sample. Thus the local extension if included in the total vitiates a comparison of the ductile qualities of the two samples. A stronger case is presented by a comparison between a long and a short specimen of the same material. Taking one sample 10 inches long and another 2 inches long, both of them giving 20 per cent. general extension up to the climax C, they may both be assumed to give afterwards $\frac{1}{2}$ inch of further extension; in the 10-inch sample this addition contributes only 5 per cent. more to the total extension, but in the 2-inch sample it adds as much as 25 per cent., showing apparently for the 10-inch sample a total extension of only 25 per cent., but for the 2-inch sample a total of 45 per cent., although the material is absolutely identical in both. How much more then would the local extension vitiate a comparison between samples of not only unequal lengths but also unequal diameters; comparing for instance one sample 10 inches long and $\frac{1}{2}$ inch diameter with another 2 inches long and 1 inch diameter, the local extension might here make the latter appear to possess more than twice as much ductility as the former, though in reality they are identical in quality, the material being the same.

It is quite impracticable to make all samples of uniform dimensions, for the simple reason that one sample may be from a thick plate or bar, another from a thin one; or a sample may be cut from a tyre or a gun-coil or across an axle, where it is

impossible to get more than a short length; moreover in different countries where experiments are made, different measures are in use. But if the extension is given in percentage of the sample's own length, and if the portion which is due to local extension is kept out of the sum, then an expression is obtained which affords a fair comparison between any samples, no matter how they may differ in size, shape, proportion, or measurement. What has hitherto hindered the adoption of this solution for a difficulty long felt has in the writer's view been the difficulty and delay involved in stopping short during an experiment, in order to note the exact point at which the required extension should be recorded. With the autographic record however, furnished by the indicator now described, there needs no stopping of the experiment, yet the different periods of extension can be readily separated by noting the altered character of the trace on the diagram. Further by taking the area of the earlier part of the diagram, with the later portion cut off, the mechanical work done per cubic inch of the specimen can be ascertained apart from that portion which is influenced by the shape of the specimen—a mode of expression which would enable a single column of figures to give the essential comparison as to quality of material in all tests, however diverse. The plan of cutting off the later portion of the diagram has the further advantage that, in the event of a sample breaking outside the datum points marked upon it for measurement, it is not thereby precluded from a just comparison with other samples which have broken between the datum points.

In Fig. 8, Plate 4, the diagram shows a full line as traced by the pencil of the indicator, and a dotted line above it which has been plotted to show the cohesive force of the material. It will be observed that the dotted line rises to the very last, inasmuch as it is the result of reckoning the tons of load, not upon the original area of the sample, but upon the contracted area at each stage: thus at the moment of fracture, although the load had gone down to 20 tons, yet, the area having contracted 50 per cent., it follows that the cohesive force per square inch had gone up to 40 tons. This explains to a great extent the enormous strength of cold-drawn wire; for if a material with 50 per cent. ductility be drawn down into wire,

although some of its ductility will thereby have been taken from it, yet on the other hand its elastic limit and the tensile strength which it had prior to this deformation will thereby have been raised enormously. The writer is indebted to Mr. Edward Richards' paper before mentioned (Journal of the Iron and Steel Institute, May 1882, page 11) for the plotted line of cohesive force, or as it may be called "intensity of stress." This line is easy to construct from the autograph diagram by means of only two calipered dimensions from the sample; and it can be done at leisure afterwards, without having interrupted the progress of the test.

The plotted line of cohesive force has been made still easier to construct, so that only one calipering of the sample is needed, by the calculation of Professor Unwin recently given ("The Engineer," 29 May 1885, p. 419), in which he shows that, assuming the sample to be uniformly plastic throughout its length, as the writer takes it to be approximately up to the climax of resistance, then the percentage of contraction of area is equal to the percentage of elongation calculated on the stretched length of bar. It is equally true that the percentage of area lost, calculated on the remaining contracted area, is equal to the percentage of elongation calculated on the original length of bar. Having then in the typical diagram, Fig. 8, Plate 4, a bar that has stretched within its climax 20 per cent. of its original length, with a load of 24 tons per square inch of original area, we find that this load is supported by an actual area of 0·833 square inch, the lost area being 0·167 square inch, which is 20 per cent. of that remaining; and the cohesive force or veritable stress is therefore 28·8 tons per square inch, or 20 per cent. greater than the nominal stress of 24 tons, the latter being the load shown by the steelyard as though supported by the full original area. The same relation between area and length holds good throughout the period of general extension. Hence to plot a curve representing the intensity of stress, each ordinate to the curve of nominal stress, or of load shown by the steelyard, should be lengthened by a percentage equal to the ratio which its own abscissa bears to the original length of bar; and a convenient way of plotting this curve of veritable stress is the following. A scale is constructed

for the climax C which is 20 per cent. higher than the original scale; oblique lines, as shown dotted in Fig. 8, are ruled across from this enlarged scale to the original one; and the curve is plotted by taking points where the load line intersects the horizontal lines of the original scale, and transferring these points vertically to the corresponding oblique lines which form the proportionally increasing scale. Each point of this plotted curve may then be taken as correct, supposing that the sample is uniformly plastic throughout the period of general extension; in so far as it may depart from being uniformly plastic, the curve as above plotted becomes only approximate and not minutely accurate.

At the place of fracture in the typical sample the reduction of area is found by calipering to be 50 per cent. of the original area; and as the sample breaks at 20 tons per square inch of the original area, the intensity of the stress is equal to 40 tons per square inch. The scale then to be constructed for this breaking point F is twice the height of the original scale. The intermediate scale cannot however be obtained by the previous plan of ruling oblique lines, because during the local elongation the length subject to contraction of area is not constant, but becomes more and more restricted as the breaking point is approached. The concluding portion of the plotted curve therefore, between the point corresponding with the climax of resistance and the point where the break occurs, is only hypothetical as shown on the diagram, Fig. 8, Plate 4.

The consideration of this increase in tenacity, taking place concurrently with a decreasing area, explains the invariable occurrence of localised extension ensuing immediately on diminishing gross resistance. For so long as the tenacity is increasing in a faster ratio than the area is diminishing, reduction of area serves only to produce increased resistance.* Under these conditions there is a strong stability of equilibrium as to the intensity of stress throughout the sample; and should any portion stretch locally, so as to contract its area and intensify its stress in advance of the other

* See "Principles of estimating Safety and Danger in Structures," by Professor James Thomson, LL.D. Glasgow 1874 (page 9).

portions, it cannot long continue doing so, inasmuch as there ensues in that portion a resistance to further extension greater than in any other part of the sample; it will therefore refuse further extension till all the other parts have been equally extended and have set up an equal resistance. As soon however as the point is reached where the increase in tenacity goes on at no higher rate than the decrease in area, the stability of the equilibrium disappears; and if any portion of the sample contracts its area in the least degree more than the rest, it has no power of recovery, and becomes at once the weakest part, as the increase of its tenacity no longer keeps pace with the reduction of its area, nor raises its power of resistance above the other portions of the sample. The neighbouring parts remain stronger to resist extension than itself, and thus the equilibrium of intensity can no longer be restored; it becomes more and more unstable, the intensity localises itself more and more, till finally the material separates at a single plane of intensest stress. It is moreover impossible that the sample should continue stretching uniformly throughout its length after the condition of stable equilibrium is passed, for the reason that, if no accidental inequality should determine the place for local extension, then it will occur at the middle of the length of the sample, because this portion receives the least collateral support from the enlarged ends or from the friction of the gripping boxes.

Summary.— The autobiography written by every specimen of iron and steel that is strained to the breaking point in the testing machine may be epitomised as follows.

Supposing it to enter the machine in a state of ease, having no unequal stresses among its particles, its first stage is one of what has been called in this paper unyielding elasticity; it extends about 1–10,000th of its length per ton of load, but on the removal of the load it shows itself unstrained, recovering its former dimensions. During this period the equilibrium of stress is stable, and uniform throughout the sample.

Its second stage is a state of fluctuating strains and stresses. The bar yields about 2 per cent. of its length; and this strain

is beyond recovery. The pencil of the indicator hesitates and almost trembles. There would seem to be a succession of local extensions in the bar, as was lately pointed out by Professor Kennedy ("Nature," 2 April 1885). These local extensions evidently reduce the area locally in a higher ratio than the cohesive force increases; hence a condition of unstable equilibrium, which would lead at once to fracture, were it not that after a short critical interval the bar sets up increased resistance, and thus enters its third stage. Here stable equilibrium is restored; but the permanent strain increases in its ratio with every added ton, so that in the latter part of this stage the bar suffers as much extension from 1 ton as it does in the earlier part from 5 tons. During this stage the bar may stretch about 20 per cent. of its length.

The fourth stage is the last. The instability of the equilibrium recurs, but is not critical or fluctuating as in the first notable yielding of the bar. There is no indecision in the pencil, but it steadily records a rapidly decreasing resistance, accompanied by a local strain which over the part where it occurs is very much greater than in any preceding stage. For although the local extension over this part may be only 5 per cent. of the total length of the bar, it would, if contributed in the same proportion over the bar generally, be found to amount to about 80 per cent. of the original length.

Conclusion.—Finally the writer would observe that, while the autographic record gives many data for research, it appears to him to possess the following advantages of the utmost practical importance in everyday engineering.

1st. It records definitely and beyond question the load at which the material gives out in its elasticity and yields irrevocably under the stress.

2nd. The area of the diagram gives the gross mechanical value of the material.

3rd. By enabling the local extension about the breaking point to be separated from the general, it affords a means of making just comparisons between samples of different shapes. Only their

initial sectional area needs to be known, and the scale of the diagram drawn to suit it. By this simple plan, whatever the size of the specimen may have been, the diagram can be read off throughout its stages in loads per square inch.

Lastly, the apparatus that has been described is self-acting in the strictest sense of the word; that is to say, it makes its record quite independently of the manipulation of the poise upon the steelyard. The most skilful manipulation could not adjust back that poise to keep pace with the rapidly decreasing resistance of the sample just before fracture, nor with its fluctuating resistance at the first notable yielding point; but whatever position the poise may occupy upon the steelyard, whether more or less than balancing the load upon the sample, the indicator makes its own independent record, free from any errors due to imperfect manipulation. It is therefore a record of such a character that, if attached to the sample by which it is made, it would form an indisputable mechanical voucher for the accuracy of the human rendering of results.

(*For Discussion see page* 62.)

DESCRIPTION OF TENSILE TESTS OF IRON AND STEEL BARS.

BY THE LATE MR. PETER D. BENNETT, OF TIPTON.

In fulfilment of the promise made at the Spring Meeting of last year, in the discussion upon Professor Kennedy's Report on the experiments on Riveted Joints (Proceedings 1885, page 275), the writer has now the pleasure of communicating the results of the series of tests he was then making at the Horseley Iron Works, Tipton. His principal object in making these tests was to ascertain the relative effect produced on the tensile strength of a flat bar of iron or steel—

1st, by a hole drilled out of the bar to the required size;
2nd, by a hole punched $\frac{1}{8}$ inch smaller in diameter and then drilled out to the size of the first hole;
3rd, by a hole punched in the bar to the size of the drilled hole.

The details of these tests are given in the appended Tables 1 and 2. The test pieces in each series were cut from separate and complete bars; and each variety was taken from three different parts of the bars, as indicated by the test Nos. marked upon the diagram at the foot of each Table. The centre and end pieces were left unperforated, and were tested in order to supply the basis of comparison for the perforated pieces, and also in order to check the homogeneous quality of the entire bar.

Referring to Table 1 it will be seen that, when the bar of iron experimented upon was perforated by a drilled hole of $\frac{3}{4}$ inch diameter, the tensile strength across the part fractured was increased from an average of 24·54 tons per square inch of the original area in the unperforated bars to 25·26 tons in the drilled bars. When the bar experimented upon was perforated by having a $\frac{5}{8}$ inch hole punched in it and afterwards drilled out to $\frac{3}{4}$ inch diameter, the average

strength was increased from 24·54 tons to 25·28 tons per square inch of the original area across the fracture. This shows that the method of perforating the bars in these two cases did not materially affect the strength of the iron under test, both methods giving results nearly identical and slightly above the strength of the unperforated bar. But when the bar was perforated with a hole punched out to the full $\frac{3}{4}$ inch diameter, the tensile strength averaged only 19·53 tons per square inch, as against 24·54 tons in the unperforated bar, thus showing a falling off in strength of more than 20 per cent. owing to the method of perforation. Taking the strength of the unperforated bar as unity, the relative strengths of the perforated bars are as follows:—

Unperforated bar of iron	1·000
Perforated by drilling	1·029
„ „ punching and drilling . . .	1·030
„ „ punching only	0·795

In Table 2 is given a series of tests exactly similar to those in Table 1, except that the metal tested was mild steel instead of iron. The results of these tests, confirming those in Table 1, show that the bars perforated with a drilled hole, and with a smaller punched hole drilled out to the same size, were slightly stronger than the unperforated bar, but that more than 6 per cent. loss of strength ensued when the hole was punched out to the full size. The relative tensile strengths per square inch of original area in these tests are as under:—

Unperforated bar of mild steel	1·000
Perforated by drilling	1·068
„ „ punching and drilling . . .	1·059
„ „ punching only	0·935

Table 3 gives a series of tests exactly similar to those in Table 1, except that the perforated hole was filled with a rivet put in by a hydraulic machine with a pressure of 31 tons on the head. The results of these tests again confirm those in Table 1, though the putting in of the rivet diminished by about one-half the loss of strength due to perforating the bar by punching only. The relative

tensile strengths per square inch of original area in these tests are as under :—

Unperforated bar of iron	1·000
Perforated by drilling, and filled with rivet . .	1·012
„ „ punching and drilling, do. . .	1·008
„ „ punching only, do. . .	0·894

Table 4 gives a series of tests exactly similar to those in Table 3, except that the metal tested was mild steel instead of iron. The results are similar to those in Table 3, the relative tensile strengths per square inch of original area being as given below :—

Unperforated bar of mild steel	1·000
Perforated by drilling, and filled with rivet . .	1·103
„ „ punching and drilling, do. . .	1·110
„ „ punching only, do. . .	0·927

From all these four Tables alike it will be seen that the metal withstood a slightly greater tensile strain per square inch of original area across the drilled hole than it did across the unperforated bar. This no doubt was owing to the fact that in the drilled bar the slightly greater strain indicated in the Tables was reached only along the transverse diameter of the hole, and that the strain on the metal decreased along the longitudinal diameter of the hole until it was distributed over the whole width of the bar. Thus at the point where it was most severely strained the metal would receive some support from the less severely strained parts adjoining.

This conclusion is confirmed by the first six tests (1319 to 1324) in Table 5, which show that, when a round iron bar of $1\frac{1}{2}$ inch diameter was reduced in diameter to 0·84 inch at one point only, it fractured under a much greater tensile strain than when it was turned down to the same diameter throughout a length of 10 inches. The relative tensile strengths per square inch of original area in the two cases were as under :—

Round iron bar turned down to 0·84 inch diameter through 10 inches length . .	1·000
„ „ „ grooved to 0·84 inch diameter at one point only . . .	1·323

The last five tests in Table 5 show that the elongation of different test bars, all of the same length, is greatly affected by their diameter, those of larger diameter elongating more than those of smaller diameter.

Table 6 gives a series of tests made on flat steel bars to ascertain whether the method of holding the ends of the specimens under test—by grips or by pins—had any effect upon the results of the tests. The figures show that there was a slight advantage in favour of holding the ends by means of grips, instead of by pins passing through: the average breaking strain with the grips being 30·11 tons per square inch of original area, and with the pins 29·97 tons.

In Table 7 is given a series of tests on flat bars of mild steel, showing how the length of the specimen under test affects the tensile strength, elongation, and contraction of area at the point of fracture. It will be seen that, as the specimens decrease in length, the contraction of area at the point of fracture decreases also; and in consequence the tensile strength increases when reckoned on the original area, and decreases when reckoned on the fractured area. The elongation in percentage of the original length is also very much increased in the shorter specimens, owing to the fact that the greater part of the elongation in each specimen, whether short or long, takes place near to the point of fracture, instead of being equally distributed over its entire length; and as this increased elongation near the point of fracture is equal in amount both in the long and in the short specimens, it follows that it gives a higher percentage of elongation when estimated upon the whole length of a shorter specimen than it would upon that of a longer.

TABLE 1. (*see continuation on opposite page*)

Tensile Tests of Flat Iron Bars, with Drilled or Punched Hole.

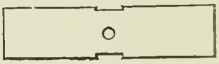
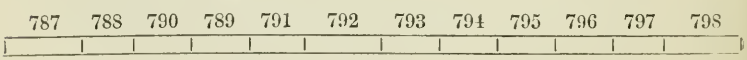
Test No.	Description and Sketch of Test Pieces. Flat Iron, 3 inches × ½ inch.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
787	Test length narrowed to 2·915 inches breadth.	2·915×0·500	1·457
792		2·915×0·505	1·472
798		2·915×0·500	1·457
788	Hole drilled 0·750 inch diameter.	2·165×0·500	1·082
791		2·165×0·500	1·082
795		2·165×0·500	1·082
789	Hole punched ⅝ inch diameter, and drilled to 0·750 inch diameter.	2·165×0·505	1·093
793		2·165×0·508	1·100
796		2·165×0·510	1·104
790	Hole punched 0·750 inch diameter.	2·165×0·510	1·104
794		2·165×0·505	1·093
797		2·165×0·510	1·104

Diagram showing order in which Test Pieces were cut from bar.



(*continued from opposite page*) TABLE 1.

Tensile Tests of Flat Iron Bars, with Drilled or Punched Hole.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Net Breadth and Thickness. Inches.	Area. Square Inch.	Reduction of Area. Square Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. inch of Original area. Tons.	Per sq. inch of Fractured area. Tons.	Ins.	Per cent.
2·340×0·375	0·877	0·580	39·8	35·78	24·55	40·7	2·80	28·0
2·335×0·378	0·882	0·590	40·0	36·02	24·47	40·8	2·89	* 28·9
2·350×0·375	0·881	0·576	39·5	35·84	24·59	40·6	2·75	27·5
				27·42	25·34			
				27·27	25·20			
				27·32	25·24			
				27·54	25·19			
				27·89	25·35			
				27·95	25·31			
				21·62	19·58			
				21·34	19·52			
				21·53	19·50			

* In Test No. 792 the extension was 2·60 inches in an original length of 9 inches.

Appearance of Fracture wholly fibrous in every one of these twelve tests.

TABLE 2. *(see continuation on opposite page)*

Tensile Tests of Flat Steel Bars, with Drilled or Punched Hole.

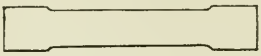
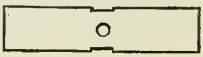
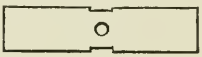
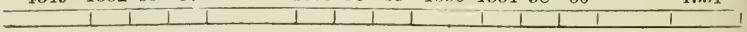
Test No.	Description and Sketch of Test Pieces. Flat Steel, $2\frac{1}{2}$ inches $\times \frac{1}{2}$ inch.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
1349	Test length narrowed to 2·440 inches breadth.	2·440×0·498	1·215
1350		2·440×0·500	1·220
1351		2·440×0·502	1·225
1358	Hole drilled 0·745 inch diameter.	1·695×0·500	0·848
1359		1·695×0·500	0·848
1360		1·695×0·500	0·848
1355	Hole punched $\frac{3}{8}$ inch diameter, and drilled to 0·745 inch diameter.	1·695×0·500	0·848
1356		1·695×0·505	0·856
1357		1·695×0·500	0·848
1352	Hole punched 0·750 inch diameter.	1·690×0·498	0·842
1353		1·690×0·500	0·845
1354		1·690×0·502	0·848

Diagram showing order in which Test Pieces were cut from bar.



(*continued from opposite page*) TABLE 2.

Tensile Tests of Flat Steel Bars, with Drilled or Punched Hole.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Net Breadth and Thickness. Inches.	Area. Square Inch.	Reduction of Area. Square Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. inch of Original area. Tons.	Per sq. inch of Fractured area. Tons.	Ins.	Per cent.
1·890×0·370	0·699	0·516	42·4	35·71	29·39	51·1	2·66	26·6
1·835×0·345	0·633	0·587	48·1	36·09	29·58	57·0	2·68	26·8
1·850×0·355	0·657	0·568	46·3	36·43	29·73	55·4	2·67	26·7
				26·82	31·62			
				26·83	31·63			
				26·73	31·52			
				26·38	31·11			
				27·05	31·60			
				26·48	31·22			
				23·30	27·67			
				23·23	27·49			
				23·62	27·85			

Appearance of Fracture wholly fibrous in every one of these twelve tests.

TABLE 3. (*see continuation on opposite page*)

Tensile Tests of Flat Iron Bars, with Drilled or Punched Hole filled with Rivet.

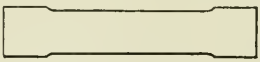
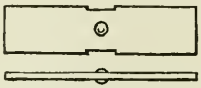
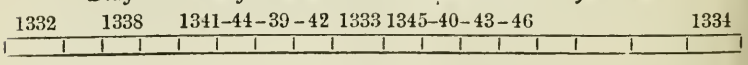
Test No.	Description and Sketch of Test Pieces. Flat Iron, 3 inches × ½ inch.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
1332	Test length narrowed to 2·930 inches breadth.	2·930×0·517	1·515
1333		2·930×0·515	1·509
1334		2·930×0·517	1·515
1338	Hole drilled 0·750 inch diameter;	2·190×0·515	1·128
1339		2·185×0·518	1·132
1340	rivet snapped with 31 tons pressure.	2·185×0·520	1·136
1341	Hole punched ⅝ inch diameter, and drilled to 0·750 inch diameter;	2·185×0·515	1·125
1342		2·180×0·515	1·123
1343	rivet snapped with 31 tons pressure.	2·185×0·520	1·136
1344	Hole punched 0·755 inch diameter;	2·175×0·515	1·120
1345		2·175×0·516	1·122
1346	rivet snapped with 31 tons pressure.	2·180×0·515	1·123

Diagram showing order in which Test Pieces were cut from bar.



(*continued from opposite page*) TABLE 3.

Tensile Tests of Flat Iron Bars, with Drilled or Punched Hole filled with Rivet.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Net Breadth and Thickness. Inches.	Area. Square Inch.	Reduction of Area. Square Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. inch of Original area. Tons.	Per sq. inch of Fractured area. Tons.	Ins.	Per cent.
2·390×0·410	0·980	0·535	35·3	39·82	26·28	40·6	2·62	26·2
2·340×0·400	0·936	0·573	37·9	39·80	26·37	42·5	2·78	27·8
2·330×0·395	0·920	0·595	39·2	39·60	26·13	43·0	2·72	27·2
				29·85	26·46			
				30·31	26·77			
				30·08	26·47			
				29·77	26·46			
				29·49	26·26			
				30·31	26·68			
				26·23	23·41			
				26·49	23·60			
				26·35	23·46			

Appearance of Fracture, 98 per cent. fibrous and 2 per cent. crystalline in 1344; wholly fibrous in each of the other eleven tests.

TABLE 4 *(see continuation on opposite page)*

Tensile Tests of Flat Steel Bars, with Drilled or Punched Hole filled with Rivet.

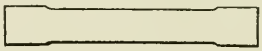
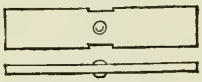
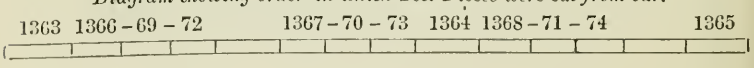
Test No.	Description and Sketch of Test Pieces. Flat Steel, $2\frac{1}{2}$ inches × $\frac{1}{2}$ inch.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
1363	Test length narrowed to 2·440 inches breadth.	2·440×0·495	1·208
1364		2·440×0·495	1·208
1365		2·440×0·495	1·208
1372	Hole drilled 0·745 inch diameter;	1·705×0·490	0·835
1373		1·705×0·491	0·837
1374	rivet snapped with 31 tons pressure.	1·705×0·492	0·839
1369	Hole punched $\frac{25}{32}$ inch diameter, and drilled to 0·745 inch diameter;	1·700×0·493	0·838
1370		1·700×0·493	0·838
1371	rivet snapped with 31 tons pressure.	1·700×0·495	0·842
1366	Hole punched 0·750 inch diameter;	1·690×0·495	0·837
1367		1·690×0·495	0·837
1368	rivet snapped with 31 tons pressure.	1·695×0·495	0·839

Diagram showing order in which Test Pieces were cut from bar.



(*continued from opposite page*) TABLE 4.

Tensile Tests of Flat Steel Bars, with Drilled or Punched Hole filled with Rivet.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Net Breadth and Thickness. Inches.	Area. Square Inch.	Reduction of Area. Square Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. inch of Original area. Tons.	Per sq. inch of Fractured area. Tons.	Ins.	Per cent.
1·900×0·370	0·703	0·505	41·8	35·64	29·50	50·6	2·60	26·0
1·865×0·355	0·662	0·546	45·1	35·69	29·54	53·9	2·60	26·0
1·885×0·360	0·679	0·529	43·7	35·46	29·35	52·2	2·74	27·4
				27·37	32·77			
				27·01	32·27			
				27·27	32·50			
				27·35	32·63			
				27·46	32·76			
				27·56	32·73			
				23·49	28·06			
				23·96	28·62			
				21·19	25·25			

Appearance of Fracture, 95 per cent. fibrous and 5 per cent. crystalline in 1366; defective in 1368; wholly fibrous in each of the other ten tests.

TABLE 5. (*see continuation on opposite page*)

Tensile Tests of Round Iron Bars,
turned down to different Diameters and Lengths.

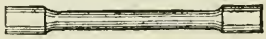
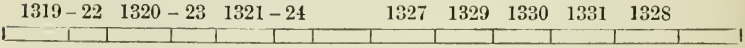
Test No.	Description and Sketch of Test Pieces. Round Iron, 1½ inch diameter.	Original Dimensions. Diameter. Inch.	Original Dimensions. Area. Square Inch.
1319	Turned down for 10 inches length to 0·840 inch diameter, being same diameter as bottom of groove in 1322 and 1323 and 1324. 	0·840	0·554
1320		0·840	0·554
1321		0·840	0·554
1322	Grooved at angle of 55 degrees, to correspond with Whitworth standard 1 inch thread, but rounded off a little more in bottom of groove. Diameter at bottom of groove 0·840 inch.	0·840	0·554
1323		0·840	0·554
1324		0·840	0·554
1327	Turned down for 10 inches length to 1·440, 1·440, 1·120, 0·755, and 0·500 inch diameter.	1·440	1·629
1328		1·440	1·629
1329		1·120	0·985
1331		0·755	0·448
1330		0·500	0·196

Diagram showing order in which Test Pieces were cut from rod.



(*continued from opposite page*) TABLE 5.

Tensile Tests of Round Iron Bars,
turned down to different Diameters and Lengths.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Diameter.	Area.	Reduction of Area.		Total.	Per square inch of			
					Original area.	Fractured area.		
Inch.	Square Inch.	Square Inch.	Per cent.	Tons.	Tons.	Tons.	Ins.	Per cent.
0·615	0·297	0·257	46·3	13·37	24·13	45·0	2·41	24·1
0·617	0·299	0·255	46·0	13·46	24·29	45·0	2·50	25·0
0·617	0·299	0·255	46·0	13·20	23·82	44·1	2·39	23·9
				17·72	31·98			
				17·62	31·80			
				17·63	31·82			
1·060	0·882	0·747	45·8	39·50	24·24	44·7	2·94	29·4
1·026	0·827	0·802	49·2	39·15	24·03	47·3	2·95	29·5
0·820	0·528	0·457	46·3	23·59	23·94	44·6	2·52	25·2
0·540	0·229	0·219	48·8	10·71	23·90	46·7	2·42	24·2
0·356	0·100	0·096	48·9	4·56	23·26	45·6	1·83	18·3

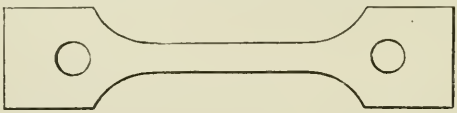
Appearance of Fracture, 90 per cent. fibrous and 10 per cent. crystalline in 1322;
„ „ 95 „ „ 5 „ „ 1323;
„ „ 15 „ „ 85 „ „ 1324;
„ „ wholly fibrous in each of the other eight tests.

TABLE 6. (*see continuation on opposite page*)

Tensile Tests of Flat Steel Bars, pulled by Grips or by Pins.

Test No.	Description and Sketch of Test Pieces. Flat Steel, 15–32nds inch thick.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
1422	Flat bars, 16 inches × 2 inches,	2·000×0·455	0·910
1423	pulled by Grips.	2·000×0·455	0·910
1424	Extension measured over 10 inches in centre.	2·000×0·460	0·920
1425		2·000×0·455	0·910
1426		2·000×0·455	0·910
1427	Flat bars, 28 inches × 6½ inches,	1·970×0·460	0·906
1428	narrowed to 2 inches over central 10 inches, pulled by Pins of 2 inches diameter.	1·970×0·458	0·902
1429	Pin-hole centres 4 inches from ends.	1·980×0·460	0·911
1430	*See sketch at foot.*	1·970×0·455	0·896

Sketch of Test Pieces 1427, 1428, 1429, 1430.



(*continued from opposite page*) TABLE 6.

Tensile Tests of Flat Steel Bars, pulled by Grips or by Pins.

Dimensions after Fracture.				Ultimate Tensile Stress.			Extension in original length of 10 inches.	
Net Breadth and Thickness. Inches.	Area. Square Inch.	Reduction of Area. Square Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. inch of Original area. Tons.	Per sq. inch of Fractured area. Tons.	Ins.	Per cent.
1·575×0·315	0·496	0·414	45·4	27·58	30·30	55·6	2·55	25·5
1·575×0·312	0·491	0·419	46·0	27·57	30·29	56·1	2·53	25·3
1·685×0·357	0·602	0·318	34·5	27·66	30·06	45·9	2·27	22·7
1·570×0·282	0·443	0·467	51·3	27·35	30·05	61·7	2·61	26·1
1·695×0·352	0·597	0·313	34·3	27·19	29·87	45·5	2·35	23·5
1·545×0·312	0·482	0·424	46·7	27·23	30·05	56·4	2·46	24·6
1·550×0·305	0·473	0·429	47·5	27·19	30·14	57·4	2·29	22·9
1·540×0·288	0·444	0·467	51·2	27·18	29·83	61·2	2·38	23·8
1·535×0·284	0·436	0·460	51·3	26·77	29·87	61·3	2·64	26·4

Appearance of Fracture wholly fibrous in every one of these nine tests.

Diagram showing order in which Test Pieces were cut from bar.

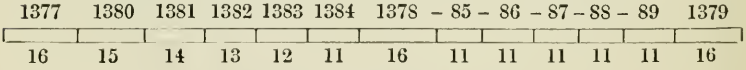
1422	1427	1423	1428	1424	1429	1425	1430	1426

TABLE 7. (*see continuation on opposite page*)

Tensile Tests of Flat Steel Bars, with different Lengths of part tested.

Test No.	Description and Sketch of Test Pieces. Flat Steel, 2½ inches × ½ inch.	Original Dimensions. Net Breadth and Thickness. Inches.	Original Dimensions. Area. Square Inch.
1377	Total length. Narrowed length.	2·230×0·490	1·093
1378	Inches. Inches.	2·210×0·485	1·072
1379	16 10	1·880×0·490	0·921
1380	15 9	1·875×0·485	0·909
1381	14 8	1·875×0·485	0·909
1382	13 7	1·875×0·485	0·909
1383	12 6	1·875×0·485	0·909
1384	11 5	1·870×0·490	0·916
1385	11 4	1·880×0·490	0·921
1386	11 3	1·880×0·488	0·917
1387	11 2	1·880×0·488	0·917
1388	11 1	1·880×0·485	0·912
1389	11 ½	1·885×0·488	0·920

Diagram showing order in which Test Pieces were cut from bar.



Lengths of Test Pieces in inches.

(*continued from opposite page*) TABLE 7.

Tensile Tests of Flat Steel Bars,
with different Lengths of part tested.

Dimensions after Fracture.				Ultimate Tensile Stress.			Original Length.	Extension in original length.	
Net Breadth and Thickness. Inches.	Area. Sq. Inch.	Reduction of Area. Sq. Inch.	Reduction of Area. Per cent.	Total. Tons.	Per sq. in. of Original area. Tons.	Per sq. in. of Fractured area. Tons.	Ins.	Ins.	Per cent.
1·685×0·322	0·543	0·550	50·3	32·80	30·00	60·4	10	2·63	26·3
1·655×0·332	0·549	0·523	48·7	32·25	30·08	58·7	10	2·62	26·2
1·400×0·328	0·459	0·462	50·1	27·69	30·06	60·3	10	2·60	26·0
1·420×0·334	0·474	0·435	47·8	27·54	30·29	58·1	9	2·34	26·0
1·390×0·330	0·459	0·450	49·5	27·66	30·42	60·2	8	2·24	28·0
1·450×0·356	0·516	0·393	43·2	27·71	30·48	53·7	7	1·85	26·4
1·420×0·330	0·469	0·440	48·4	27·75	30·52	59·1	6	1·65	27·5
1·400×0·333	0·466	0·450	49·1	27·89	30·44	59·8	5	1·38	27·6
1·405×0·334	0·469	0·452	49·0	27·96	30·35	59·6	4	1·32	33·0
1·465×0·355	0·520	0·397	43·2	28·11	30·65	54·0	3	1·00	33·3
1·485×0·364	0·541	0·376	41·0	28·26	30·81	52·2	2	0·77	38·5
1·535×0·361	0·554	0·358	39·2	29·42	32·25	53·1	1	0·49	49·0
1·630×0·344	0·561	0·359	39·0	30·11	32·72	53·6	½	0·27	54·0

Appearance of Fracture wholly fibrous in every one of these thirteen tests.

Discussion.

Mr. WICKSTEED exhibited a large number of specimens which had been tested in the machine, and to which their respective self-recorded diagrams were attached. He also showed a volume containing a collection of various test diagrams from samples of iron, steel, copper, brass, and delta metal.

The scale of stress in the self-recorded diagrams was of course created by the elasticity of the indicator spring; and he had therefore been particularly anxious to establish its correctness. The spring was 15 inches long, and had a range of 5 inches, being one-third of its length. Throughout its range it was supposed to be perfectly elastic, in the sense that it would contract equal distances for equal additions of load; if this was not the case, the scale would not be correct. For establishing its correctness, the following mode was adopted. The poise-weight was set to begin with at 1 ton on the steel-yard, and the water pressure was applied until the lever floated. As soon as the lever floated, a pencil mark was ruled across the diagram paper, by pulling the indicator barrel round. In the same way a second mark was made on the paper at 10 tons stress; and ultimately, when the maximum carrying power of the specimen was reached, good care was taken to have the lever floated again, so as to mark correctly on the paper the exact position corresponding with the maximum load. In this way three positions were marked on the paper which were ascertained with absolute correctness from the steel-yard itself. The zero or base line was not obtained in the same way as the three foregoing, because allowance had to be made for the initial friction of the leathers; it was therefore fixed at a distance below the 1 ton line equal to one-ninth of the distance between 1 ton and 10 tons. The paper bore therefore a base-line correct by inference, a correctly ascertained maximum line, and an accurately ascertained line at 10 tons. Then supposing the maximum load on the sample were 24 tons, the total height of the diagram was carefully divided into 24 equal parts; and if the tenth

division hit upon the line which had been accurately ascertained to be the position of 10 tons, a positive proof was thereby obtained that the scale was a correct one; because it could not be correct at the top, and correct at the bottom, and correct also at an intermediate place, without being correct throughout the whole of its subdivisions. This he believed was the most important point to which he had paid attention since the preparation of the paper.

With reference to the wavering and falling off in the load at the elastic limit or critical point B in the diagram, Fig. 8, Plate 4, this feature in the diagram must be attributed in his opinion to the peculiar behaviour of iron and steel. It could not be attributed to any peculiarity of the machine or of the recording apparatus, because, if instead of iron or steel a piece of delta metal or copper or brass were tested in the machine, no such fluctuation was then found at that point in the diagram; and if two samples of the same material were tested, the second never repeated the first exactly in its behaviour at that point. There were very noticeable differences to be seen in the behaviour of almost all the individual samples, although the general characteristics were the same for the same metal.

Professor Alex. B. W. Kennedy said the automatic drawing of a stress or strain diagram would be an exceedingly simple thing if the pull in the specimen could be made to increase continuously; but unfortunately always at the climax C in Fig. 8, Plate 4, and very commonly also at B as pointed out by the author, there were fluctuations: the stress at those points underwent a falling-off, which was peculiar to the particular material tested, and quite independent of any method of manipulation. The real difficulty of designing apparatus such as that described in the paper was met with at those points in the diagram, and lay in the means of providing some measurement for stress which should be independent of the position of the weight on the steel-yard, because the weight itself did not automatically move back along the steel-yard at those points. So far as he knew, Mr. Wicksteed's exceedingly ingenious and workmanlike apparatus—which no doubt most of the members had seen last year at the Inventions Exhibition, if nowhere else—was the first machine in

(Professor Kennedy.)

which the behaviour of the material both at the elastic limit and at the maximum load was automatically registered; it was at least the first that had come to his own knowledge in which both those points were autographically recorded. He was therefore especially glad that the Institution should now be enabled to introduce into its proceedings the author's own description of so highly important and ingenious an apparatus.

In regard to the friction of the leathers on the main ram, it had been stated in the paper that, after their initial resistance had been deducted, the friction was exactly proportional to the total pressure, and so affected only the scale of the diagram. This was just a point with regard to which no opinion was worth anything until it was based on experiments such as had been made by the author; and he therefore felt bound to accept it. At the same time he should be very glad if the records could be given of two or three sets of measurements such as were referred to on page 31, so that it might be seen within what limits of accuracy that statement was exact.

As to the elimination of the friction of the indicator ram in its longitudinal movement, by the expedient of keeping it revolving, it was rather stretching a point to say that absolutely no friction would then be left to come into play longitudinally. The cause of the disappearance of longitudinal friction from the ram when it was made to revolve he considered was simply the alteration of the direction in which the surfaces were rubbing upon each other. Each point on the surface of the revolving ram, instead of simply moving longitudinally, was really moving in a very finely pitched screw. If the ram simply revolved without moving longitudinally at all, there would be no longitudinal friction, because there would be no longitudinal component of motion along the axis. It was the longitudinal friction that had to be got rid of, not the circumferential; and he imagined that the ratio of the former to the latter must be equal to the ratio of the pitch of the screw motion to the circumference of the ram; and as the ram revolved at considerable speed, while longitudinally it moved very slowly, the pitch of the screw motion was a very fine one. The amount of the friction to be encountered longitudinally was therefore not zero, but some small

fraction of the whole friction on the ram; and no doubt it could be reduced so much that it might practically be neglected.

The greater part of the work he had himself done in regard to elasticity had been in connection with the behaviour of materials under such loads as occurred actually in practice. For this purpose he was afraid there was as yet no autographic apparatus capable of rendering very much help; because the fluctuations of strain which occurred within the range of elasticity from A to B in Fig. 8, Plate 4, were so very small that they did not even appear at all in that diagram; and they had to be magnified so enormously before they were made visible that so far as he knew they had not been autographically registered in any satisfactory way. But he had been so much struck some time ago with some of the diagrams which Mr. Wicksteed had been good enough to show him, especially with the autographic record of the elastic limit or breakdown point at B in Fig. 8, that last spring he began again seriously to try to scheme for his own use a diagram-drawing apparatus, his previous attempts in that direction having come to nothing. His reason for not adopting Mr. Wicksteed's plan had been, not that he had any objection to it on principle, but mainly that it was too expensive for the limited resources available in his own case. He had therefore decided upon utilising a plan that he had previously adopted for other purposes, namely putting into the testing machine two bars "in series," as electricians would say: one bar to be tested or broken, and another bar which might be called a spring-piece, being made so much stronger than the test-piece that when the test-piece was broken the spring-piece should still not be strained beyond its limit of elasticity. He had put his roughly sketched plans into the hands of his friend, Mr. A. G. Ashcroft, by whom they had not only been worked out into the apparatus now exhibited to the meeting, but had also been so greatly modified and improved that his own interest in them was not any longer paternal, but merely friendly and critical. As shown in the drawings of the apparatus, Figs. 13 to 15, Plate 7, the test-piece T and the spring-piece S were arranged horizontally in line with each other, and secured together by a screwed joint J, and pulled endways. Two

(Professor Kennedy.)

spring clips C_1C_2 were fixed as gauging points, one on each end of the test-piece, at ten inches apart, or whatever the length to be tested might be. The extension on that ten inches was communicated to a sheet of smoked glass G sliding in a frame F fixed upon the spring-piece S; any increase in the distance between the two gauge points C_1C_2 caused the sheet of glass to slide towards the test-piece T. The lever and sector arrangement LMN through which this motion was communicated was of a differential nature, and served the purpose of making the motion of the glass entirely independent of any possible give in the screwed joint J, or any extensions in any other part of the apparatus than the part between the two gauge points C_1C_2 on the test-piece. The lever L, centred at its lower end upon the frame F, was pulled in the middle of its length by a rod connected with the nearer clip C_2; and on its upper end was centred the sector M. The rod N from the further clip C_1 actuated the sector by means of a silk thread, attached by each of its ends to the rod and wrapped round the shorter arc of the sector; and the glass G was pulled forwards by a silk thread H from the longer arc, and was pulled back by another thread K passing over a pulley on the frame to a counterweight. The distance through which the sliding glass moved was equal to twice the extension of the test-piece. On the extremities of the spring-piece S were clamped at UU the outer ends of two rods, of which the inner or meeting ends carried two saddles VV sliding freely past each other along the spring-piece. Across the saddles lay the axis or centre pin R of a light brass pointer or vibrating arm P; and each saddle carried a silk thread, attached by each of its ends to the saddle, and wrapped round the axis R. By this means the extensions of the spring-piece moved the pointer P; and the angular movement of the pointer was in proportion to the extension of the spring-piece. In this particular spring-piece he had previously ascertained that, up to its limit of elasticity, or at least as far as the load which would break the test-piece, the extension was proportionate to the load: so that the part AB of the diagram corresponding with Fig. 8, Plate 4, was a straight line. That was not so of course for all materials; nor was it always so for every individual piece of any particular

material. But for this individual spring-piece he had found that it was so, having tried it several times. Consequently the angle moved through by the pointer, being proportional to the extension of the spring-piece, was proportional to the pull in the spring-piece; and therefore also to the pull in the test-piece, because the pull in the two was the same. Accordingly the pointer arm vibrated up or down on its centre through an angle exactly proportional to the real pull in the test-piece, no matter where the weight was on the steel-yard which produced the pull in the test-piece; and at the same time the glass slid horizontally alongside the pointer in proportion to the extension of a known length upon the test-piece itself. The pointer scraped the smoke off the glass; and after varnishing the diagram so got, the smoked glass could be used as a negative, and prints, such as those shown in Fig. 16, Plate 8, could be photographed directly on blue paper in the ordinary way. The drawback in this arrangement was that the motion of the pointer was of course in a circular arc, and consequently the diagram had not a straight axis of stress, but was like the old curved indicator diagrams produced by Mr. Gooch's indicator. That result was inherent in this particular form of apparatus; and it was a disadvantage which he was afraid it would be difficult to overcome. Thus far the apparatus had not been adapted for any test-pieces which had to be held in wedge grips; probably that might come afterwards, but at present its use was limited to particular forms of test-piece. The delicacy of the apparatus rendered it peculiarly sensitive at the point corresponding with B in Fig. 8, Plate 4, representing the elastic limit. It would be seen that some of the diagrams in Fig. 16, Plate 8, showed the stress line going back at that point by an amount equal in one case to 15 per cent. and in another to 13 per cent. of the whole load.

The labour involved in constructing non-autographic diagrams, on which some stress had been laid by the author, was not perhaps so serious after all, especially as non-autographic diagrams had to be constructed under any circumstances for the part of the test before the limit of elasticity was reached. The mechanical work expended on a test-piece was no doubt in many respects a most excellent measure of the value of a material. As he had pointed out on a

(Professor Kennedy.)

previous occasion,* it was very easy to get an approximation to the area A B C F, Fig. 8, Plate 4—that is, to the whole mechanical work expended on the test-piece—by means of a simple formula which included only the measurements always given to engineers, namely the maximum stress and the total extension and the ratio of the limit of elasticity to the maximum stress. The following were a few results showing the comparison of the measured areas of such diagrams as those shown in Fig. 16, Plate 8, with the calculations so made.

Test No.	Steel or Iron.	Work in Inch-Tons per cubic inch.		Error per cent.
		Actual.	Calculated.	
5400	Basic Steel Plate . .	5·49	5·57	+1·5
5401-2	„ „ . .	5·33	5·21	−2·3
5401-1	„ „ . .	5·91	5·67	−4·2
8397	Perkins' Steel Bar .	5·26	5·12	−2·7
9047	Landore Rivet Steel .	7·56	7·09	−6·1
9048	„ „ .	6·29	6·17	−2·0
8391	S.C. Crown Bar Iron .	4·85	4·55	−6·3
8592-3	Rivet Iron . . .	4·47	4·52	+1·2
9461	Swedish Bar Iron . .	5·00	4·94	−1·3
9462	„ „ . .	5·29	5·44	+2·7

It would be seen that occasionally there was a difference of 6 per cent.; more generally the difference was only 2 or 3 per cent. It was well for engineers to know that there was a mode of getting the total work done in breaking a test-piece, not accurately but with a reasonable approximation, from data which were entirely at their own command.

---

* See Proceedings of the Institution of Civil Engineers, 1882, vol. lxix., page 30. The formula there given may be written, $work = s\,x\left(\frac{r+2}{3}\right)$, where s is the maximum load per square inch of original area, x the total extension in inches, and r the ratio $\frac{\text{limit of elasticity}}{\text{maximum load}}$. This gives the work in inch-tons (or inch-lbs. &c., as the case may be) on the tested length of the given material if it were one square inch in cross section. Divided by the tested length in inches, it gives the work per cubic inch.

The proposal to measure the extensions upon a length which did not include the short portion near to the place of fracture was of course an old one. He had himself adopted, as he had no doubt many others had done, the plan of dividing into inches the total length of the test-piece before testing it, marking the inches upon the piece itself, so that the extension in any number of inches, not including the inches near the place of fracture, could after the test be separately measured if required. He was rather surprised that engineers generally did not more often want that measurement of the extension, which, as shown in Mr. Wicksteed's paper, was a most important matter.

In comparing specimens of different shapes, he presumed Mr. Wicksteed meant to limit the comparison to specimens of similar section. It would not hold good, he thought, between a square and a round section, for instance; and this he believed was a general opinion among engineers.

Mr. Wicksteed did not know that the shape of the section made any difference up to the commencement of local extension.

Professor Kennedy mentioned, in regard to the concluding paragraph of Mr. Wicksteed's paper, that there was at least one instance of manipulation sufficiently skilful to adjust back a poise fast enough for keeping pace with the decreasing resistance of the test-piece just before fracture; for he had himself had the good fortune to see this done by Professor Unwin in his testing apparatus, about which he hoped something would be said on the present occasion.

With regard to Mr. Bennett's paper, the experiments recorded in his tables showed that in all cases the drilling of a hole through the test bar had resulted in that excess of tensile strength which had already been discussed at previous meetings. What he wished now to point out was that the excess in these experiments was sometimes rather small, on account of the test-pieces having flat sides and a circular hole drilled through the middle. It was a well-known fact that the excess was always greater in a test-piece shaped like

(Professor Kennedy.)
the portion of plate between two adjacent rivet holes along the line of a riveted joint: that is, in a test-piece bounded by two semicircular arcs, one on each side, and without a hole through the middle. From his own notes of some experiments of this kind he found that test-pieces, such as those used by Mr. Bennett, gave 34½ tons; while pieces of the same material and area, bounded not by flat sides, but by semicircular arcs corresponding with the sides of two rivet holes, gave 36½ and 37 tons. He had read the experiments given in Mr. Bennett's paper with very much interest, and he was glad they had been presented to the Institution.

Mr. CHARLES COCHRANE wished Professor Kennedy would supplement his last remarks by pointing out how the increase of tensile strength was the result of the shape of the material. To himself it was difficult, though it might not be so to others, to see how, after a bar or plate had been drilled with a hole through it, the increase of tensile strength per square inch arose in the material that was left.

Professor KENNEDY said he had not anything further to add in reply to that question beyond the explanation which he had already attempted on previous occasions (Proceedings, 1881, pp. 217–218; 1885, pp. 287–288).

Mr. BENJAMIN WALKER considered the apparatus described in Mr. Wicksteed's paper would be found very useful indeed in connection with the manufacture of steel. Iron was not so uncertain or so irregular as steel. Steel of the very highest qualities would now and again show most fantastic behaviour. The autographic test-recording apparatus would act as a sort of policeman, checking the quality of the material by showing what was the load actually carried, and also what was the rate of extension at the same time. There was some steel that he would trust without any fear as to the consequences, so long as the load upon it was steady and uniform; but there was other steel with regard to which he should require to be very sure that it possessed sufficient elasticity and stretching

power before he should be satisfied to trust it. This testing machine enabled a steel-maker to discriminate one kind of steel as suitable for a concussive strain, and another for a steady strain: the one as suitable for a piston-rod, and the other for a slide-bar. Where the strains were concussive, sudden, and uncertain, steel capable of a large amount of extension was the best. Sir Joseph Whitworth had been quite right in calling the attention of mechanical engineers to the fact that the combined estimate of the quality of steel, by what it would carry and what it would extend, was the correct mode of measurement for that material.

In confirmation of the statement made in page 31 of the paper—that the friction of the hydraulic leathers appeared to be uniformly proportional to the water pressure—he remembered that some ten or twelve years ago the late Mr. George Wilson of Sheffield had undertaken to make some very large links of flat steel for a bridge in America, which were required to be tested. A large number of these links had already been completed, and a number of beautiful test-pieces had been received from Mr. Kirkaldy, showing the excellent quality of the metal, as proved by its high breaking strength and the large extent of its stretching in these samples. But the samples were not accepted, and it was required that each separate link should itself be put into a testing machine, and tested to carry a certain fixed load. At that time there was no machine in the country that would carry such a load as was required; and he had therefore been engaged to make a testing machine for the purpose. As no steel-yard that he knew of could be constructed to carry the load required, it was decided to employ a pair of hydraulic rams of 20 inches diameter, placed horizontal and moving a crossbeam, to which was attached the link to be tested. The friction of the glands of the rams was arrived at by a species of approximation, whereby a very fair test was obtained of each link, the test load being of course applied after the glands had been screwed up water-tight. One of the glands was packed with a cup leather, and the other with common hemp packing. In order to arrive at the friction of each gland packing, each gland in turn was gradually screwed up very carefully until it just stopped leaking while carrying an

(Mr. Benjamin Walker.)

experimental load; then the load was taken off, and by means of a steel-yard the exact weight was ascertained that was required to move the unloaded ram through the gland. The experimental load was successively increased, the glands successively tightened up to be just watertight, and the increasing friction successively measured in the same manner, until the full amount of the required test load was reached. In this way it was found that the friction of each packing alike was most uniform, increasing in regular proportion with the load moved by the rams. By this means the bridge links of 10 or 12 feet length were satisfactorily tested to the required load. As a further check upon the friction of the glands, the water pressure on each ram was noted by three pressure-gauges, and the total force was thus calculated; then the amount of the dead test-load being deducted, the difference represented the friction of the packings, and confirmed the results obtained with the steel-yard as to the uniform increase in friction with the increasing pressures.

He was quite sure there would be yet more to be heard of the machine described in the paper. Even if it was not yet so far perfected as to be useful in the hands of a common workman, it was clearly the right beginning and in the right direction; and he had no doubt that ultimately these machines would be employed to act as policemen in steel works, for testing the quality of the steel.

Professor W. CAWTHORNE UNWIN said he was much obliged to Professor Kennedy for the remark he had made about keeping the lever floating during the test, because the evidence of an independent witness was better than anything that he himself could say. The fact was that with three specimens out of four, if ordinary pains were taken, the lever could be kept floating throughout the whole of the test, and the whole of the diagram to the very end could thus be drawn with apparatus which was connected with the poise-weight. In certain specimens however he must admit that Mr. Wicksteed was quite right in saying that this could not be done. With a very ductile bar it was not possible to keep the lever floating during the whole of the test, although it was possible to get over that difficulty in a way which was quite satisfactory. The experiments he had made

in that direction had led him to doubt very much whether even with Mr. Wicksteed's form of apparatus, or with his own, it was possible to get at all a perfect registration of the part of the curve at B in Fig. 8, Plate 4, or the final part of the curve from the climax C down to the point of fracture F. But it was very doubtful whether this was a matter of any particular importance. It so happened that in 1882 he wanted a large testing-machine; and between that time and the present Mr. Wicksteed had made two 100-ton machines for him, one for Cooper's Hill and one for the Central Institute, both of which were very fine machines. One of the reasons which had determined him in selecting this machine was that he saw from the first that it lent itself very conveniently to the application of an autographic apparatus which would not in any way interfere with the ordinary processes of testing. During the last three years Mr. Wicksteed and himself had been in constant communication upon this subject; they had both been working at the same problem, but had come to two different solutions of it.

Engineers generally he thought were not at all aware how much had been done in the direction of getting autographic diagrams. The first machine, as far as he knew, was that of Professor Thurston in America; it was perfect in principle, but he thought it did not give very perfect diagrams. It was however an exceedingly interesting machine; and it brought out in a very striking way one peculiarity in the behaviour of metals, namely the rise of the elastic limit after removal and re-application of the load above the stress previously on the bar. Two or three different machines had also been made in America, by Fairbanks and others; and two or three also in Germany, of different types again. He had himself constructed one machine; his successor at Cooper's Hill had constructed another; and Professor Kennedy had arranged the beautiful machine now exhibited, the principle of which he had previously understood, although he had never seen it till now, and in some respects it was better than any of the others. A good deal therefore had been done in that direction. The peculiarity and originality of Mr. Wicksteed's autographic apparatus lay in his having taken the indication of the load not from the poise-weight, from which

(Professor Unwin.)

it was ordinarily taken, but from the pressure in the main hydraulic cylinder. When Mr. Wicksteed first told him that he was going to work in that way, he confessed he had not expected him to succeed as well as he had done; for he had really made a very great success of the plan which he had adopted. What occurred to himself as an objection to going that way to work was that in that plan the thing which was directly measured was the pressure in the main hydraulic cylinder. Now that pressure was made up of several items. The whole pressure P in the cylinder was made up firstly of the tension T on the test specimen. In the second place it comprised the constant pressure C, which was due to the unbalanced part of the counterbalance weight attached to the piston-rod of the main hydraulic cylinder. Thirdly, while the piston was moving there was the friction F of its own cup leather, and of that through which the piston-rod worked. Fourthly, there were some smaller items of friction f due to certain guides, and to the journals of the rather heavy counterbalance weight, and to the pin joints connecting it with the piston-rod. Fifthly, there was an item which at first sight it might be thought ought to be omitted, namely the inertia I of the moving parts. In the 100-ton machines supplied to himself, he believed the weight of the whole mass that moved with the piston was between 2 and 3 tons. Now if that weight changed its velocity of motion at all, its inertia came into play; and though the change of motion was not very quick, the weight was very heavy. The inertia he thought did not at all affect the diagram generally, that is from A to B in Fig. 8, Plate 4, and also through the greater part of the line from B to C: but he believed it did affect the diagram to a certain extent in the two parts he had mentioned, namely the short fluctuation immediately following the point B, and also the falling line from C to F. Finally there was also a very little friction in the pipe connecting the indicator cylinder with the main hydraulic cylinder; but this might be neglected, because only in certain cases would it be of any importance. The whole pressure P in the main hydraulic cylinder was therefore seen to be made up as follows:—

$$P = T + (C + F + f + I)$$

It would here be seen that Mr. Wicksteed was obliged to assume

that all those quantities which he did not want to measure—namely the four items enclosed within the brackets in the above expression—formed together a constant percentage of the tension T on the specimen. At first it looked as if this must be impossible; and his first view of the apparatus, when he heard of the method Mr. Wicksteed was going to adopt, before the machine was constructed, was that it would be impossible to get a very good result in that way. On the whole however he believed a very good result had thereby been obtained. By certain slight adjustments of the counterbalance weight acting on the hydraulic piston, and of the initial tension of the indicator spring, a load scale was obtained on the diagrams which certainly was tolerably constant all the way from 1 ton up to 50 tons. He was therefore quite ready to admit that the difficulty had been nearly conquered by Mr. Wicksteed; though the fact that some adjustment was necessary constituted he thought an objection to that type of machine, because it was impossible to be certain that those adjustments would remain always constant, both in themselves and in their effect, and that the person in charge of the machine always took the trouble to see whether the adjustments had changed or not.

The uniformity of the load scale in Mr. Wicksteed's diagrams had been determined by experiments, in which, before the mark was made with the pencil, care was always taken to get the piston into motion downwards. As long as this was done, the load scale so obtained was tolerably uniform. But with that apparatus it was not possible to do what could be done well with his own:—namely, reverse the direction of motion of the piston, and still keep the load scale equally uniform. This was no great objection to the machine as a practical one, because the difficulty had been nearly conquered in the way already explained by Mr. Wicksteed; but from a purely scientific point of view this apparatus was not quite so satisfactory as one in which the indication of the load was taken with equal correctness whether the poise-weight was being run backwards or forwards.

The arrangement of the wire in its course from the test specimen to the indicator barrel was identical with that in the Polmeyer machine

(Professor Unwin.)

which he had seen in 1883 at Dortmund, with the exception of the ingenious pair of radius-links which had been added by Mr. Wicksteed. The principle of those links was absolutely perfect, and consequently no bodily motion of the specimen affected in the least the proper indication of the elongation. In the first machine which he himself had constructed he got seriously involved in the difficulty that the bodily motion of the specimen relatively to the indicator barrel affected the indications. The difficulty in that case had been very serious, because for various reasons he had chosen to put the indicator barrel on the short arm of the poise lever, and when the lever moved up and down there was a good deal of motion to deal with. He therefore found another method of compensation, also perfect in principle, by which the unnecessary motion was got rid of and a true motion was given to the pencil. But by placing the indicator barrel in the right position relatively to the specimen, with diagrams of the size taken by Mr. Wicksteed or of double that size such as those taken by himself, there was not the slightest need of any compensating arrangement such as the pair of radius-links. There was one plane in which the specimen had no transverse motion, but only a small up and down motion—namely the plane of the knife-edge from which the specimen hung; and by leading the wire from the specimen parallel to the knife-edge it was possible to do without any compensation whatever. He had found that, even with diagrams of the size that he took, no movement of the specimen occurring from any movement of the lever produced any measurable distortion of the diagram. He had taken a great number of diagrams of the kind shown in Fig. 17, Plate 9, in which, after having reached a certain load, the poise-weight had been run back, and the stress on the specimen diminished; the pencil then ran down a vertical straight line, as at M and N, which was so perfectly straight that a straight-edge placed against it showed no deviation. Putting the weight on again, the pencil ran up again over the very same line. Any motion of the specimen which affected the diagram would be shown on that vertical line; because, if the motion of the specimen affected the diagram in any way, it affected it in the horizontal direction, that is, it affected the measurement of elongation.

In some scores of the diagrams which he had taken he had never found those vertical lines show the slightest sign of a loop, although they had been traced in the two directions—down and up again. This was a pretty sensitive test of the fact that it was possible to lead off the wire, for diagrams even of the size he employed, in such a way that no compensation was wanted for the movement of the specimen. It would be noticed how at the points M and N in Fig. 17, Plate 9, the diagram showed the rise of the elastic limit beyond the previous load.

Passing from the recording apparatus to the rest of Mr. Wicksteed's paper, he did not absolutely dissent from anything that it contained, but a few things he thought had been stated much too positively. He heartily wished everything stated in the paper was strictly true, because the estimate of the quality of a material would then be rendered somewhat easier than it really was. From many materials the diagrams obtained were not so nicely shaped as that shown in Fig. 8, Plate 4. In many cases flat-headed diagrams were produced, in which the determination of the climax C was more difficult.

Mr. Wicksteed said that was true; and explained that, in enlarging from the original autograph the typical diagram shown in Fig. 8, Plate 4, the line just preceding the climax C had purposely been drawn rather steeper than ordinary, in order to bring out more prominently what he meant by the climax at C.

Professor Unwin observed that the method of using as a measurement of the quality of the material the mechanical work done in producing its fracture had been proposed long ago by Mr. Mallet. Mr. Wicksteed had also proposed to take only the work done in breaking the specimen up to the climax C; and had given certain reasons—good reasons as far as they went—for considering that this portion of the work done furnished a better representation of the quality of the material, than if the whole work up to the final rupture were taken into account. That suggestion again was not a new one, having been made several times before. It

(Professor Unwin.)

had been dealt with very fully in a careful paper by Professor Hartig (Proceedings Inst. Civil Engineers, 1884, vol. lxxviii., pp. 462–4), by whom it had also been applied rather fully. In Mr. Wicksteed's paper no figures had been given for showing whether by taking the work only up to the climax C any discrimination was obtained of the quality of a material. It had simply been stated that figures so arrived at would afford such a discrimination, and he himself was by no means sure they would not; but the matter wanted yet a good deal more investigation, and he would give a few figures which he thought might perhaps cause a little hesitation before accepting definitely the method proposed to be adopted as a test of the quality of the material. These figures had been worked out by Professor Hartig, exactly in Mr. Wicksteed's way, for a series of steel bars containing severally the following percentages of carbon:—0·14, 0·19, 0·46, and 0·54 per cent.; showing therefore a pretty wide range in the quality of steel. The work done in breaking those bars, estimated up to the climax C, Fig. 8, Plate 4, in kilogrammetres per gramme of material—which was exactly Mr. Wicksteed's way of calculating, though with different units—came out respectively 1·12, 1·11, 1·11, and 1·14; so that it would be seen that this test of the quality of the material showed nothing whatever. He did not mean to say that such a result would always occur; but it was rather surprising that the work came out so very constant for such very different materials.

Mr. WICKSTEED considered it showed that the stiffness made up for the want of extension.

Professor UNWIN said that was so; but if engineers wanted for a structure steel containing 0·14 per cent. of carbon, they would not like, in consequence of the work done up to rupture being the same, to get one without knowing it that had 0·54 per cent. of carbon.

Other figures, which were perhaps even more startling, had also been obtained by Professor Hartig by estimating the work expended in rupturing a number of different materials. Taking the work done up to the climax C, it had thus been found that phosphor-bronze

was better than mild steel; that whalebone was very considerably better than phosphor-bronze; that raw silk was better than whalebone; and that vulcanised rubber was six times as good as steel.

Mr. Wicksteed asked whether Professor Hartig's comparison meant weight for weight, or section for section, of the different materials. Would the rope of silk be the same weight per foot run as the bar of steel? Or would the transverse sectional area be the same in both?

Professor Unwin replied that the work done was given in kilogrammetres per gramme of the material tested, and consequently the comparison was between equal weights of the different materials.

Mr. Druitt Halpin considered a great step in advance had been taken by the introduction of the autographic apparatus, although he did not altogether like its form as described in the paper so well as Professor Unwin's, which he thought had less errors of friction and worked more correctly. But in regard to self-recording machines generally and the diagrams they gave, it would be a very great advantage he considered if any means could possibly be devised for producing what might be called a sort of reversal of the diagram represented in Fig. 8, Plate 4, so as to magnify the amount of the horizontal extension within the elastic limit from A to B, and make this portion occupy as great a horizontal length on the diagram as from B to C or from B to F. The subsequent extension, after the elastic limit had been passed at B, was not wanted to be shown on any larger scale than at present; for he regarded the extension from B to F as merely a matter of curiosity, to show what happened when once the elastic limit at B had been passed. What engineers wanted to know was what the material would do during its life, and not any vagaries it might go through after it had passed into its death throes. It was of course a very difficult matter to magnify to so great an extent as he had hinted such extremely small quantities as the minute extension within the elastic limit; but when it was recollected that one-millionth of an inch could be measured by the Whitworth

(Mr. Druitt Halpin.)

machine and other suitable apparatus, the hope need not be abandoned of accomplishing a matter of such great moment as the magnifying of these minute extensions. That would be greatly preferable to giving a large diagram for the remainder of the test, which was really not wanted.

With regard to the other factor involved in the production of the test diagram—namely the position of the poise-weight on the lever, and the consequent amount of the load—he had seen both Professor Kennedy and Professor Unwin work the lever testing-machine, and they both did it so beautifully as to keep the lever floating. But they themselves would be the first to value any appliance by which the lever could be kept floating automatically. The case seemed to him exactly the same as that of a steam-engine indicator. What would be the use of an indicator diagram if the string were pulled by hand, while watching the motion of the piston-rod and judging by eye whereabouts the cross-head was? The test-recording apparatus he hoped would be made as automatic in this respect as was already the case in the steam indicator.

With regard to the coefficient of mechanical value, referred to in page 35 of the paper, the coefficient obtained by adding together the load and the extension, as proposed by Sir Joseph Whitworth, had been taken up by the German Union. But this was a figure that had never had any value to his own mind, as he did not see what it had to do with the question. If however the extension were multiplied by the load, instead of being added to it, the coefficient so arrived at would possess some value.

As to the length of test-pieces, unfortunately testing-machines were as yet very rare, and when engineers had to test material at works they generally had to do it without the advantage of these machines. It would therefore be much better he suggested if a universal length could be adopted for test-pieces; and to his mind the most convenient length was $12\frac{1}{2}$ inches, for this reason, that it consisted of one hundred eighths of an inch, and by means of the two-foot rule which every engineer carried he could very easily measure eighths of an inch.

Mr. Thomas Turner, referring to Table 5 in Mr. Bennett's paper, considered the results given in the three tests Nos. 1322–3–4, where the round bars had been simply grooved, were very interesting, and showed the necessity for engineers to specify the length of the turned portion which they required to be tested. But the tests here given were from iron bars; and he had had one or two made from steel bars and from composite bars, which would compare with these and show rather different results. The first six tests in Table 5 showed an increase of 32 per cent. in the tensile strength of the bar grooved with a narrow groove at one point only, as compared with the same bar when turned down to the same diameter through a length of 10 inches. In round bars of mild steel, of the same size and similarly turned, he had found the increase in tensile strength by grooving amounted to 43 per cent.; and to 38 per cent. in a composite bar formed of steel with strands of iron running through it for the purpose of obtaining a fibrous character and ease in welding.

Referring also to the last five tests in Table 5, which showed much less elongation and slightly less tensile strength per square inch of original area when the bar was turned down small, it could hardly be expected from the method of the manufacture of iron that tests of iron bars would always give similar results. Iron was not homogeneous, and it might happen that the centre of the pile from which the bar had been rolled had been puddled from a different pig from the outside. But steel was fairly homogeneous, and therefore the comparison of the centre of a steel bar with the outside was fair. He had known cases of iron bars being turned down small, and giving then a higher tensile strength than was obtained before turning; but generally with a smaller diameter of bar the elongation was less, for the reason stated in Mr. Wicksteed's paper, namely that the local extension was less, because of the smaller diameter.

In a mild steel bar of the same size as the round iron bar tested by Mr. Bennett, he had found that by turning it smaller the tensile strength, instead of decreasing, increased considerably as follows:—

Diameter of mild steel bar when turned down, inch .	1·31	1·12	0·75	0·50
Tensile strength per sq. inch of original area, tons .	24·8	25·9	27·0	28·0
Elongation in percentage of original length, per cent.	28·7	25·2	25·0	25·0

(Mr. Thomas Turner.)

It seemed curious that the centre of a steel bar should thus be found stronger than the outside; and it was difficult to explain the reason. The only suggestion he could offer was that it might be due to the internal stresses set up within the bar during cooling, because of course those internal stresses would be more likely to produce results of that kind in a homogeneous material than in one which was not homogeneous. In testing composite bars similarly turned down he had obtained the following results:—

Diameter of composite bar when turned down, inch .	1·25	1·12	0·75	0·50
Tensile strength per sq. inch of original area, tons .	26·1	26·0	25·9	26·1
Elongation in percentage of original length, per cent.	28·0	27·0	22·4	22·5

In this case therefore it would be seen that there was practically no difference in tensile strength between the centre of the bar and the outside.

Mr. CHARLES COCHRANE considered engineering practice was at present in a transition stage in regard to the use of steel instead of wrought-iron in structures in which it had not been the practice hitherto to use steel, especially in girder work; and he thought it was of the greatest importance to mechanical engineers that they should have a testing machine which could be adopted throughout the engineering world, and on which an engineer in London, for example, could rely to furnish him with trustworthy results as to materials tested at places where he was unable to be present. Hitherto the testing machines had been of very variable make, and had been deemed to be uncertain in their results: so much so that specimens in large numbers—not in tens but in hundreds—had to be sent up from the provinces to London, in order to be tested by machines specially constructed, and accepted as reliable by engineers in London. It was therefore of great importance he thought to know of such a testing machine as Mr. Wicksteed's: so that, whether at works at which the steel or wrought-iron was manufactured, or at works where bridges were constructed of either material, the testing done by such a machine might be accepted as reliable, without the useless expense of sending

to London in order to have the materials tested. One of these machines he believed had been adopted by Mr. Bennett at the Horseley Iron Works, and had been used by him for making the tests described in his paper; and he understood the London engineer or engineers who were concerned in the work that was being carried on there had been perfectly satisfied to accept in London the tests recorded by this machine in the country. A great move he considered had thereby been made; and he hoped one of Mr. Bennett's sons was present to bear testimony to these facts.

Great service he considered had been rendered by Mr. Bennett in establishing the comparative results of punching and of drilling, and of punching and drilling combined. It must be a great source of satisfaction, and must have its due weight with all engineers, to find that steel as well as wrought-iron could be first punched and then drilled, not only without any deleterious influence on the plate or bar, but apparently with a little advantage to its tensile strength. It was certainly very extraordinary that it should be so; but all the results tended in that direction, both with the punching and drilling combined, and with the drilling alone—namely that the tenacity of the material so treated was absolutely a little greater per square inch than that of the original plate or bar out of which the holes were so drilled. Why the material left after the drilling should be stronger per square inch than the same material before the hole was drilled, was a question which he understood had not yet been thoroughly solved, although the matter had been discussed at previous meetings of this Institution as well as elsewhere. No special experiments he believed had been made upon the ultimate section of the material and its extension before fracture; but he thought it would be found that the ultimate section was really greater when buttressed up or supported by adjacent parts, as referred to in page 46 of Mr. Bennett's paper, than it was when the material was allowed to be equally subject to extension throughout the whole length of the piece tested. Nevertheless it seemed puzzling to explain how a round bar having a little groove turned round it would carry more per square inch before fracture than if the whole bar were turned down to the same

(Mr. Charles Cochrane.)
diameter as the groove. This was a question which he hoped at a future time some one would be able to solve, as he believed it had not yet been solved completely.

Mr. HERBERT B. S. BENNETT said he could confirm Mr. Cochrane's statement in regard to the use of one of Mr. Wicksteed's testing machines at the Horseley Iron Works with the autographic apparatus; and it certainly did give most valuable results. The whole of the tests contained in the tables forming his father's paper had been carried out in that machine; and he exhibited an extensive collection of the autographic diagrams taken in these tests as well as in many others.

Mr. THOMAS TURNER suggested that the reason of the increase in tensile strength consequent upon drilling a hole through a test bar was the same as the reason of the increased tensile strength obtained when the bar was notched down in width along each edge through a length equal to the diameter of bar: namely that the length actually tested was thereby shortened. And as to why the tensile strength should go up in consequence of shortening the length upon which the test was taken, there was a suggestion in page 46 of Mr. Bennett's paper that the tensile strength was increased in the drilled bars because of the support which was received from the extra section that was so close to the point of fracture; and with this explanation he was disposed to agree. The increase in tensile strength he therefore considered was not a question of drilling, or of punching first and drilling afterwards; it was simply because the length really tested was thereby so greatly shortened.

Professor ROBERT H. SMITH thought a proof of the skill with which the design of Mr. Wicksteed's autographic apparatus had been worked out was supplied in the statement that according to careful measurement the proportion between the rise of the pencil upon the diagram and the actual increase of load was found to be constant. If indeed that proportion were accurately and absolutely constant, it would show that all the difficulties of this very complicated problem

had been perfectly got over; but inasmuch as in any testing or experimental work the results rarely came out with anything like absolute accuracy, it would be interesting to know within what degree of accuracy the proportion was found to hold, or what was the magnitude of any small errors which might have been observed. In the means here adopted for moving the pencil in proportion to the load, it seemed to him that an unnecessary difficulty had been dealt with. The plan of merely connecting the pencil direct with the moving jockey-weight was not only much simpler, but he thought for all practical purposes it was also sufficiently accurate.

The most ingenious part of the author's arrangement was in his opinion the rotation given to the small ram in order to overcome its friction through the gland, which appeared to him to be a device of very high merit for overcoming friction at such a joint. The fact being proved that the difficulty of friction was thereby practically got rid of at that particular part of the mechanism, the question arose why this result was obtained. The explanation that occurred to himself was the following. Friction was a force which always opposed motion; and the direction of the frictional force was exactly opposite to that of the motion. Now in the gland there was only a certain amount of frictional force to be overcome. The author's device was to make the direction of the motion almost wholly circumferential, and therefore the frictional force was almost wholly in the circumferential direction also. Consequently the resolved component of the frictional force in the longitudinal direction was extremely small; and therefore the rotation of the ram enabled it to move endways readily, in response to the slightest variation of end pressure upon it from the fluctuation of the load.

The mechanism consisting of the horizontal and vertical radius-links for conducting the wire from the test specimen to the indicator barrel, so as to rotate the barrel in proportion to the extension of the specimen, was mathematically perfect. But from a practical point of view he was a little afraid lest the friction of the wire in passing over the three pulleys that intervened in its course might involve some slight variable extensions of the wire, which might be inconvenient; and he should like to know whether any measurable

(Professor Smith.)

error had been found to arise from that source. Having lately been using very fine wires for similar purposes in recording instruments, he had found the friction of the pulleys so great in comparison with the extensibility of the wires that he had everywhere endeavoured as far as possible to do without any pulleys at all, and to lead the wire direct in a straight line from beginning to end of its course.

The final portion of the autographic curve, from C to F in Fig. 8, Plate 4, he agreed with the author in thinking was of very little value. This portion of the curve, so far as he knew, had first been shown distinctly some nine or ten years ago by Professor Thurston's autographic apparatus for twist tests. In that apparatus he considered the character or shape of this part of the curve was chiefly due to the character of the mechanism. Reference had been made in the paper to the difficulty of keeping the lever floating during this part of the curve; but even though in some cases it was found possible to do so, yet the mere fact of the lever being kept floating did not show that this part of the curve was really characteristic of the material; and he thought it was much more characteristic of the testing machine than of the material which was being tested. In order to keep the lever floating, the jockey-weight had to be run back along the lever at a certain definite rate corresponding with the rate at which the water was being pumped into the main hydraulic cylinder; and if the water were pumped in at a slightly fluctuating rate, the immediate result would evidently be to throw the lever against the upper or the lower stop, if the jockey-weight continued to be run back at the same rate as before.

Mr. WICKSTEED explained that it was essential the water should come in at a uniform rate. The pump was worked from the main shaft driven by the engine, which was governed; and it might be assumed as true that the water was throughout coming into the pulling cylinder at a uniform rate, no matter whether the resistance was great or small.

Professor SMITH said in that case, if the jockey were run backwards along the lever at a rate varying from that needed to

maintain equilibrium, while the water was pumped in at a uniform rate, the result would evidently be still the same, namely to throw the lever against the upper or the lower stop. Therefore the shape of the curve from C to F, in Fig. 8, Plate 4, depended on the rate at which the jockey was run backwards relatively to the rate at which the water was pumped in. A similar case was that of a small testing machine used by himself, in which the test-piece was pulled by means of worm gear and screw, and the pull was conveyed to it through a large spring-balance, indicating up to nine tons only. When the final stage was reached, there was of course in that kind of apparatus very great difficulty in keeping the full force up while the test-piece was yielding so much faster. In order to keep the full tension upon it, there would be required practically unlimited power of varying the speed of rotation of the screw by which the test-piece was pulled. As a matter of fact in most experiments he had found it impossible to keep the pulling force always up to its original amount; and the proportion between the continually increasing extension of the test-piece and the slightly decreasing magnitude of the pull was evidently a function, not only of the increasing extension of the piece itself, but also of the decreasing length of the spring through which the pull was conveyed. Exactly the same thing occurred in the apparatus which had been shown by Professor Kennedy. The character of the curve drawn by that apparatus beyond the climax of resistance must depend upon the modulus of elasticity of the strong spring-piece S in Figs. 13 and 14, Plate 7. The final portion of the curve from C to F in Fig. 8, Plate 4, he therefore thought was of very little value indeed as a practical indication of the character of the material. The same remarks applied also to the drop in the diagram immediately after the elastic limit had been reached at the point B in Fig. 8; this drop he considered to be characteristic of the design of the testing machine and of its manipulation only, and not characteristic at all of the nature of the material tested.

It was certainly a most interesting and important fact which had been stated by Professor Unwin, that the mechanical work expended in producing rupture, as represented by the area of the autographic

(Professor Smith.)
diagram, was the same for different specimens of steel with such different degrees of carburisation. While thinking therefore that it was highly desirable to record the quantity of this mechanical work, he altogether agreed with Professor Unwin that by itself it could never be looked upon as a complete test of the character of the material. It was necessary to see the actual curve itself throughout its whole length, and not merely to know its area, in order that the extensibility and other characteristic qualities of the material might be completely understood.

In reference to the assumption (page 39) of uniform plasticity up to the climax of resistance in a test sample, its real meaning, as stated and used in the paper, was simply that when the sample was elongated its volume remained constant. This however was not supported by the most careful experiments that had been made upon that special subject. The experiments of Wertheim showed that the volume always increased under a tensile stress in the case of the three materials on which he had experimented, namely iron, brass, and glass. It seemed to himself that all materials would become greater in volume when they were subjected to a tensile stress; but he could not say that this was the necessary result in all. There might be some special materials which might become contracted under tension, in consequence of the ratio of contraction in area being greater than the ratio of elongation; but he believed that in all the plastic materials which engineers had to do with for constructive purposes the volume really did become greater under tension.

At the Mason Science College, Birmingham, he was using an apparatus for testing the rate of flow of specimens under a constant load, that is, the relation between the increase of strain and the time that had elapsed after the constant load had been put on: this relation being one which he considered of great importance, and which had not yet been sufficiently investigated. The strain was communicated from the specimen by means of a very fine phosphor-bronze wire to a pencil, which marked a curve upon a piece of paper mounted on a drum; and the drum was made to revolve at a uniform rate by the weight of a plunger in a small cataract filled with

glycerine; by closing or opening more or less the cock of the cataract the rate of rotation of the drum could easily be regulated to any speed that was most convenient for the special experiments in progress. This plan was more convenient than ordinary clockwork, because of the great facility with which the rate of motion of the paper could thereby be varied.

Mr. John A. F. Aspinall said he had been using one of the 50-ton testing machines made by Mr. Wicksteed's firm, and had been trying some experiments in the same direction as the author for the purpose of getting an autographic test-recorder. The arrangement he had devised, as shown in Figs. 20 to 25, Plates 10 and 11, consisted simply of a horizontal indicator barrel D, carried upon two parallel horizontal bars B, so as to permit it to slide backwards and forwards; and a pencil P was similarly carried in a slide mounted upon the same parallel bars, so that the pencil could travel either forwards or backwards along the indicator barrel, irrespective of the independent longitudinal movement of the barrel itself. The pencil was connected by means of a cord or wire L with the lower end of the test-specimen S, and the barrel was similarly connected with its upper end by another cord U. The rotary movement was given to the barrel by means of a cord R from the poise-weight W, through the intermediate reducing gear G. This arrangement certainly seemed to give a very nice and apparently an accurate diagram, as shown full size in Fig. 19. Of course as soon as the climax of resistance had been reached at the point C, there arose the objection which had been pointed out by the author at the end of the paper, namely that there was a certain amount of difficulty in winding the poise-weight back by hand so as to keep it exactly in the proper position in relation to the work that was then going on in the specimen, and thereby to keep the lever floating. But it was a question in his own mind whether this final portion of the diagram from C to F was really worth having at all. Surely when the point had been reached at which the specimen might be said to yield absolutely and finally, any further information was scarcely wanted, at any rate for ordinary purposes. In the last part of the curve, from

(Mr. John A. F. Aspinall.)

C to F, was simply recorded what went on in the specimen after it had become like an attenuated streak of treacle. The apparatus he had described had been found to do very well for enabling test-diagrams to be taken rapidly in testing pieces of boiler plate; and it certainly had the advantage of being uncommonly cheap and simple.

Mr. THOMAS W. TRAILL remarked that, after so much had already been said about the very neat autographic instrument described in Mr. Wicksteed's paper, he would merely express his own opinion that it was an apparatus of which the author need not be ashamed. The testing machine to which it was applied had proved a very useful one to steel manufacturers. It was a machine which could do its work quickly, although perhaps doing it too quickly might not do fair justice to the material. That however would not be the fault of the machine, but of the person working it, and wanting to get too much out of it.

With regard to the paper by the late Mr. Bennett, he fully shared the sorrow felt by all the members at the event which had prevented their having the benefit of the author's presence on this occasion. Had Mr. Bennett been spared, he thought it more than probable that he would have supplemented his paper with a few further remarks to pretty much the same effect as those which it now occurred to himself to make. From the tests recorded in Table 7 the conclusion was drawn that the contraction of area was less in short specimens; and no doubt this was the fact when the length tested came down to 1 inch. From 10 inches down to 4 or 5 inches length it would be seen that the contraction was pretty constant at about 48 to 50 per cent.; and only when the tested length was reduced to 1 inch did the contraction fall to 39 per cent. On this point engineers who were not experienced in testing might come to a wrong conclusion; for although it was certainly most essential that test-specimens should be prepared with due care and be properly proportioned, yet it was evident from these particular results that no practical error would accrue from taking the contraction when the length was about 5 inches instead of 10.

Nevertheless he was himself a strong advocate of the 10-inch length, as used by the author, instead of the 5-inch or any other length less than 10 inches. The 10-inch length had many advantages, and was a good English standard length; moreover it required no calculation to get the percentage of elongation, thus saving both the time and the trouble of calculating and also the consequent risk of error. It was desirable that as far as practicable a uniform length should be adopted for test-pieces, for enabling comparisons to be made; and a 10-inch length was that which he thought most English engineers of experience would prefer. Too frequently the percentage of elongation was mentioned, without the length in which it was taken being stated: such information was not only of no value, but it might be misleading. For an elongation of 25 per cent. in 5 inches was inferior to the same percentage in 10 inches, because the elongation was both general and local, and the local elongation was nearly a constant quantity. Therefore if the total elongation was 25 per cent. in a test-piece 5 inches long, and was also 25 per cent. in another test-piece of 10 inches length, this did not indicate that the two pieces were equal in ductility; on the contrary it showed that the material of the 5-inch piece was inferior in ductility to that of the 10-inch piece. Possibly some of those who adopted a short length for the test-pieces might like to adhere to that practice, because a high percentage of elongation sounded well. When the test-piece was 10 inches long, the elongation could be measured near enough with a two-foot rule, because no practical engineer would cavil at a trifling variation of only 1 per cent. less or more in regard to the elongation, or a total variation of only 2 per cent.

Another point to which he thought the author would probably have drawn attention more fully than he had done in the paper, if he had extended his experiments a little further, was the injurious effect of the punch. It was true that the tests recorded in Table 2 showed a loss of 6 per cent. in the tensile strength of mild steel bars after punching; and certainly even 6 per cent. was a loss which engineers did not like to incur. But coming to the thicker steel plates which he had himself had occasion to test, he was sorry to say that the loss through punching was not confined to 6 per cent., but was something

(Mr. Thomas W. Traill.)
like 25 per cent. or more, which was a very serious thing indeed. Moreover not only was there so great a loss in tensile strength, which if known might be provided for, but in addition the steel was so injured by the effect of the punch that in the neighbourhood of the punched hole it became brittle and like glass: so much so that there was no reliance to be placed upon a piece of steel after such a barbarous tool as a punch had been through it.

Mr. ALFRED A. LANGLEY desired to confirm the remarks of Mr. Traill about punching: it was a barbarous process, especially when applied to rails, for which it was much in vogue for putting bolts through them for the fish-plates. In his own experience he had had an immense number of rails with their ends broken, and nearly always broken through the punched hole. He had accordingly caused them to be drilled with an oblong hole; and since then no rail ends had broken. It was a favourite saying that punching formed a sort of test for the rails; but it was so poor a test that it was of very little consequence compared with the importance of using rails that could be depended upon.

With regard to the autographic registering apparatus on the testing machine, he had himself been using extensively an autograph pen for recording the movements of a railway carriage both longitudinally and transversely. The pen made a mark on a paper disc, which was caused to revolve by means of a clock; and every movement of the carriage, whether lengthways or crossways, was thus registered automatically. After each hour the paper disc was taken off, and the pen went on recording upon a fresh paper every movement caused by the imperfections of the road and of the carriage.

Mr. HENRY ROBINSON asked how it was that, with a total pressure of $52\frac{1}{2}$ tons on the main piston in the author's testing machine, the margin of $2\frac{1}{2}$ tons, or only 5 per cent., was sufficient to overcome the friction of the hydraulic leathers surrounding both the piston and the piston-rod; whereas for the small indicator-ram the friction of the gland alone had been given as one-sixth of the total pressure on the ram, or 16 per cent.

Mr. Wicksteed replied that the difference was owing to the very small size of the gland, which made the friction greater in proportion to the area of the indicator-ram.

Mr. E. H. Carbutt, M.P., recalled the time when the quality of a piece of iron used to be judged entirely by the sight; even for the best Yorkshire iron the only mode adopted was to have it broken and to judge by the fracture whether it was good or bad. Those days had gone by, and at the present time every ironworks had its own chemist for analysing the composition of the iron or steel manufactured. Apart from chemical analysis, Mr. Wicksteed's excellent machine now gave a mechanical analysis, of which every detail was accurately recorded in autographic diagrams. The question of both chemical and mechanical analysis he considered was one of the utmost importance. A subject was at the present time before the government, which was of vital importance to the country, namely the defective bayonets in the army. It appeared that the bayonets supplied to the troops had been defective to the extent of one-third. If the troops went into battle and one-third of them were not able to do their duty because their bayonets were defective, what a loss of strength that would mean to this country, or what a cost it would be to have an army one-third bigger than would otherwise be necessary. If a supply of proper bayonets were ensured by the aid of chemical and mechanical analysis, there would be no such trouble as had been experienced in the Soudan war. It was therefore of the utmost importance that mechanical engineers should give their best attention, as Mr. Wicksteed was doing, to the means of obtaining all possible information concerning the qualities of the different kinds of steel they were using.

In reference to the drop shown in the autographic diagram, Fig. 8, Plate 4, at the point B where the elastic limit was reached, he did not quite understand why the line after rising up to 17 tons at that point should then go down again to 16 tons, unless it was that the skin resistance was equivalent to a certain amount of hardness, and when that skin resistance had gone, a certain amount of strength had gone with it.

Mr. Wicksteed said that in Mr. Bennett's paper there was one statement which he thought deserved special attention, because he believed it was the first time it had been put forward in any authentic manner: namely that a test-specimen pulled by grips had actually done a little better than a similar specimen prepared with enlarged ends and with holes bored through them for pulling by pins. It had often been maintained that in order to get the best results it was necessary to make an extravagantly expensive specimen, beginning with a very wide strip for the sake of getting large ends with pin-holes through them, and then reducing the width very greatly indeed over the portion between the datum points. In the discussion upon his former paper on this testing machine (Proceedings 1882, pages 402-3) he had expressed the opinion that, if the machine itself was in perfect alignment so as to induce no cross strains upon the sample, there could not be a more favourable method of holding the sample than by ordinary parallel grips. This view he was very glad to see substantiated by Mr. Bennett's experience in the use of one of these testing machines specially designed for testing by means of grips. It was only if a testing machine was used of rude construction, and it was wanted to make a sort of universal joint for the sample to adjust itself upon in default of the true alignment of the machine, that there was any advantage at all in having enlarged ends with big pin-holes through them. With grips swivelling in grip-boxes, all tooled and properly fitted in alignment in the machine itself, no cross strains were induced in the sample, and it was pulled true in parallel lines from top to bottom by the grips closing upon its ends; and the ends themselves were either exactly the same width as the part between the datum points, or they were only a very little enlarged.

Passing to the remarks which had been made upon his own paper, the question had been asked why the autograph line in the diagram Fig. 8, Plate 4, descended at B after the elastic limit had been reached. He had not the remotest notion, and could not explain it in the least; and he doubted very much whether any satisfactory explanation could yet be given. Of the fact of the drop he was thoroughly convinced, and he thought the explanation would

ultimately be found in the molecular behaviour of the material. Special attention was being devoted to that particular part of the diagrams by Professor Unwin, by whom he had no doubt that in the end the matter would be fully elucidated; but it was so far from being understood at present that the drop had been spoken of by Professor Smith as a function of the machine only, and not of the specimen tested. In direct opposition to that view he himself maintained that it was not a function of the machine, but that it was a true record of the molecular stress in the specimen. This he maintained on the grounds that in the very same machine he had tested specimens of copper, of brass, and of delta metal, from which diagrams were shown in Figs. 10 to 12, Plates 5 and 6; and it was seen that the line ran up as smoothly and steadily from the elastic limit at B as in any other part of the diagram. Moreover occasional specimens of wrought-iron or mild steel would draw a straight horizontal line from the point B through two-tenths of an inch extension in a specimen ten inches long, as shown in Fig. 9, Plate 5; and sometimes this horizontal line would be ruled perfectly straight, with no zigzag, no depression, no irregularity. With yet other specimens of wrought-iron or mild steel the line on passing the elastic limit would start off at once in a rising curve, without making any horizontal jump at all. With Professor Kennedy's beautiful instrument he was delighted to find very good diagrams which showed the same thing. Although that instrument looked so different from his own apparatus, the two were each based upon essentially the same principle. In Professor Kennedy's the stress was measured by the elasticity of a straight steel bar; in his own it was also measured by the elasticity of a steel bar, but here the bar instead of being straight was coiled round and round into a helical spring. The consequence was that the spring of 15 inches length was composed of a bar that was three times 15 inches long; and he thought the molecular action on the bar when in the form of the spring was of the most favourable kind possible, being of the nature of torsion. As pointed out by Professor Kennedy, it did not follow that, because the straight bar in his instrument gave a true elastic stretch, that is an equal amount of stretch with an equal increment

(Mr. Wicksteed.)

of load, therefore every straight bar did so; and neither did it follow that, because this coiled spring gave a correct scale, therefore every such spring would do so. All he need say was that there was here a spring at one end of the apparatus, and at the other end a steel-yard which was absolutely correct, and against which therefore the spring was checked throughout its entire range. If any spring was found not to give a correct result in agreement with the steel-yard, it could be rejected and another tried. Hitherto he had been fortunate, having got springs of the same character as were used for a Salter's weighing machine; he had not had to reject any spring, and in subdividing the height of the test-diagrams in the manner already explained, he had found that the lines which ought to coincide did really cover each other. What the degree of microscopic accuracy was he did not know; but as the scale was a small one, he considered it might be reckoned to be correct well within a quarter of a ton. Alike in his own apparatus therefore and in Professor Kennedy's the stress was shown by an elastic bar, which in the latter would bear a very great stress, but gave very little motion; and accordingly in that case, in order to produce a diagram, the motion had to be multiplied perhaps a hundredfold, the point of the pencil that pressed upon the smoked glass having probably a radius of something like a hundred times that of the cylindrical needle which was rotated by the silk cord as the bar extended. Corresponding with that, in his own apparatus the spring gave all the motion for producing a good-sized diagram without multiplying gear; but the spring itself was pressed upon by a stress which, by the difference in the area under water pressure, was reduced to one-fiftieth of the stress coming upon the specimen; and this was the distinctive feature in his own plan, which enabled a manageable spring of ample range to be used, instead of a strong bar giving only microscopic extensions. Still the two instruments he considered were based on the same principles, though his own application of those principles was kept free from any delicate multiplying gear involving the use of a smoked glass for minimising the resistance of the trace, and straight lines were obtained for the ordinates in the diagrams.

In respect to the friction on the wire transmitting the extension of the sample to the indicator barrel, he had found it was a very great difficulty indeed to catch the very first microscopic extension that took place in the specimen. To have succeeded in doing so he considered a very great feat, because the friction of motion was different from the friction of rest; and although there was a weight hung on each end of the wire, yet, as soon as the specimen began to stretch, the wire's first tendency was to straighten itself a little, and not to transmit to the indicator barrel that first extension of the specimen. But as the lines upon which the whole of the apparatus had been constructed were not at all delicate, the whole being made very strong, the wire was infinitely fine in proportion to the strength of all the other parts. The weight hung at each end was about as much as it would bear. The response was certainly very prompt; with good eyesight a horizontal departure could be traced in the extension line from the very first ton of load. There was no loss of motion, because the barrel was kept up by the counterweight hanging below it; and as soon as ever the specimen began to extend, the barrel responded. This was one of the difficulties that had had to be tackled. It was true that all the friction which could be eliminated from the system would increase the perfection of transmission; but convenience in use had also to be studied, and in spite of the three pulleys and the angle of 180° the transmission as arranged had approached wonderfully near perfection in actual practice. While fully appreciating however the value of Professor Smith's observation on this point, he would remark that the principle of the compensating pulleys would equally apply if the wire were led almost straight from the sample to the indicator barrel. It was immaterial that there should be 180° between the two ends of the wire; 90° would do, or even 10°, if only there were angle enough to allow for the general movements of the sample. The great advantage of having got a transmitting gear theoretically right to begin with, was that then considerations of convenience could be allowed to determine the position of the indicator barrel, and a little more work could be put upon the transmitting gear with impunity.

(Mr. Wicksteed.)

With regard to the question which he was very glad Mr. Robinson had raised about the friction, it certainly did look at first as though there were some mistake. But the figures given in the paper as to the friction of the indicator-ram were the result of actual observation. Its friction had been found really to form as large a proportion as one-sixth of the whole pressure on the area of the ram. Being $1\frac{1}{8}$ inch diameter, the ram had an area of only 1 square inch against a circumference of $3\frac{1}{2}$ inches rubbing in the gland. But the main hydraulic piston of 9 inches diameter had an effective area of 50 square inches against a joint total circumference of only 40 inches for the piston rubbing in the cylinder and its rod rubbing in the gland. It was thus clear that the proportion borne by the friction changed entirely as the size of the ram changed: so that, whereas in the main cylinder the combined friction of both the piston and its rod was approximately only one-twentieth or 5 per cent. of the whole pressure on the piston, yet in the gland of the indicator ram it amounted to as much as one-sixth or 16 per cent.

To his intercourse with Professor Unwin for some years past he was greatly indebted for many of his own ideas in connection with this apparatus; and also for some of the details, which had proved very useful. Among the latter were the small clips which had been shown to him at Cooper's Hill for attaching the wire to the sample tested; and these were what he had adopted for the purpose. They had a vertical knife-edge on one side, and the points of two set-screws on the other side. The vertical knife-edge steadied the clip from tilting or skewing vertically, and the two screw-points steadied it from skewing round horizontally. So that with a reasonable amount of nipping to begin with, and a spring that followed up and closed upon the specimen as it became attenuated, a firm clip was obtained, which preserved its horizontal position.

The recording apparatus described by Mr. Aspinall was a very beautiful arrangement; and was of the same character as Professor Unwin's, with some exceptions. In one respect he thought that Professor Unwin's was better, on account of its being free from the sag of the long horizontal wire; for in Mr. Aspinall's the wire was dragged out horizontally by the poise-weight as it ran out along the

lever, and there would undoubtedly be some little sag in the wire when the poise-weight was getting towards the end of the lever of 16 or 20 ft. length. In Professor Unwin's apparatus the sag of the wire was obviated by taking the motion from the poise-weight in another way, which answered the same purpose and was perhaps subject to less error. But anyhow Mr. Aspinall's recording apparatus he considered was certainly a very great success, and the diagram shown from it in Fig. 19, Plate 10, was identical with his own diagrams; only just at the very end it seemed to have missed the final record at the moment of rupture.

There was one great difference that occurred to him to point out in comparing the arrangement described in the paper, which was his own notion of what a self-recording apparatus ought to be, with Professor Unwin's and Mr. Aspinall's: namely that theirs could not do what Mr. Walker had said that his own did—act the part of a policeman. Those machines could really be made to draw whatever curve was wished, by simply travelling the weight along the lever, irrespective of whether the sample supported the lever or not. It was quite enough to know that the diagrams were drawn by Professor Unwin and Mr. Aspinall themselves, to feel satisfied that they were correctly drawn; but it would not be enough to know that a diagram was drawn with the same apparatus, if that apparatus was sent into the country to take the place of an inspector. In this respect he thought the perfectly self-acting nature of his own apparatus, which could not be coaxed into making a line in any way different from the actual water pressure that was putting the stress upon the sample, constituted so far a practical advantage. Still he considered Professor Unwin might perfectly well argue that in his own hands he should place every reliance upon his own apparatus, because it carried with it a check, ton by ton: so that he should know absolutely that, when the poise-weight was pointing to 25 tons, the connecting mechanism must be marking 25 tons on the diagram; and it did not require anything further than one trial of the mechanism to prove this. The remarks of Professor Smith, as to the position of the poise-weight affecting the curves of the diagrams, might apply to recording apparatus on this principle; but had no application to his

(Mr. Wicksteed.)
own, which drew its curves wholly irrespective of the behaviour of the lever.

The seemingly recondite question of the inertia of the moving parts in the testing machine had not really to be taken into consideration at all. For it must be borne in mind that the rate at which the water was entering the pulling cylinder was maintained uniform throughout, as a necessary consequence of the construction of the machine. The pump was not a plunger pump, but a screw pump. The screw being revolved by belt and gearing was steadily forcing forwards a horizontal ram, which in its turn was forcing the water at one uniform rate into the pulling cylinder. Whether the stress on the sample fell off towards the end, or whether it was maintained, made no difference in the rate of advance of the pulling piston, which inevitably went on advancing, whether it met with no resistance at all, or with the maximum resistance. Therefore the inertia of the pulling piston, the inertia of the counterbalance tail-weight, and the friction of the pin on which the tail-weight was hinged, were all constants—not a constant percentage, but a constant absolute amount, this being the initial friction spoken of in page 31 of the paper as being balanced by the initial pressure put upon the indicator spring. The water column in the pipe making fluid connection between the main cylinder and the indicator cylinder was almost stationary, the pipe having a good sized bore; and there was nothing small about the testing portion of the machine. At any rate the pencil was so lively that sometimes it dropped faster than it could be followed by eye, when a test-piece gave out in stress; and at the breaking of the sample the indicator-ram went home like a shot.

The PRESIDENT understood there was no moving back at all of the poise-weight along the lever during any part of the autographic diagram from the commencement at A to the climax at C in Fig. 8, Plate 4. If therefore the lever was kept floating during the whole of that period, and did not go down upon its lower stop when the line sank after reaching the elastic limit at B, the curve from the point B to the same level on the opposite side would have to be made almost instantaneously.

Mr. Wicksteed replied that it was not so quick as that, and the lever did sometimes go down on the stop at that part of the diagram; but this recorder was not dependent on the floating of the lever. The width of the gap at B when testing mild steel was generally two-tenths of an inch in the 10-inch specimens. The rate of motion might be timed to any speed that might be thought proper, and substantially the same result was still obtained; the rate might be so slow that it took a minute to travel through that extension of two-tenths of an inch, and the pencil would then gradually creep down the drop and up again. In order however to dispel any question as to whether the autographic curves were at any part a function of the machine—whether they were due to the dynamical effect of the moving poise-weight at the end of the lever—he had taken a good many diagrams with the poise-weight stationary at the far end of the lever, so as to keep it down, over-balancing the pull on the sample, and keeping perfectly stationary the whole mechanism from which the sample was held, thereby leaving the water to tell its own tale without any floating weight; and in all cases he had got substantially the same curves.

There was no difficulty, such as Professor Smith had experienced, in keeping up the pulling force; for the sample did not yield any more than there was pulling force to make it yield; and the curve was a record of the yielding of the sample, together with the amount of pulling force exerted simultaneously with that yielding. The pull in this machine was at a uniform rate; but when the sample began to give out after having passed the climax of resistance, then to increase the rate of pulling, as suggested by Professor Smith, would only make the sample yield the faster, and the character of the curve would remain the same.

The observations of Professor Smith incidentally pointed to the desirability of keeping the steel-yard free from motion; and in this he himself entirely concurred, believing it to be an important feature of his apparatus that it enabled testing to be conducted entirely free from the influences of a moving steel-yard, and also that it would act more instantaneously than the adjustment of a poise could be effected. Where one of these recorders was employed, the testing operation as he recommended it to be performed would become entirely automatic.

(Mr. Wicksteed.)

The poise-weight would be at the extreme end of the lever, where it would hold the lever down at rest. The recorder would produce a trace on scaled paper which was absolutely reliable, inasmuch as that very scale had been constructed from the steel-yard itself, as described in the paper, and could be verified from the steel-yard every day or every hour or at every test if required.

The adjustments of this indicator were not in the least degree delicate or troublesome. In fact there was only one adjustment to make at any time, and that was to screw up the indicator spring till its pressure balanced the initial resistances of the machine, which were all constants. This adjustment could be tested for accuracy, as described in the paper. Many thousands of diagrams had been made where these recorders were in operation at various works, and no part of the apparatus had been found subject to derangement. The effect of combining this recorder with any testing machine was that a scale of load was thereby obtained at each end of the system: at one end it was a steel-yard lever and dead weight; at the other end it was a water lever and a spring. The action of the one was as reliable as of the other, only that the value of the water lever and spring could not be proved except by the application of dead weight; and hence the need of the steel-yard for evaluating the net stress resulting upon the sample from the motion of the water lever and the spring.

In regard to the use of the diagram when made, it had been remarked by Professor Kennedy that the proposal to measure the extension upon a length which did not include the short portion near the place of fracture was of course an old one; and it had been mentioned by Professor Unwin that this point had been dealt with very fully by Professor Hartig. The importance of that method was thereby confirmed, and the diagram made by his own apparatus furnished the means of carrying out that method with exactness and rapidity. In the latter part of the paper it was shown, he believed for the first time, how the diagram could be cut off as with a knife just where the local extension began; and why it was that localised extension was certain to be found concurrently with a falling load. It was quite true that, by giving the value of materials per cubic

inch in a single column of figures, it was only the quality termed "resilience" that would be compared; but this was a valuable comparison to make, and it could be made very readily by the information which an autograph diagram afforded. The suggestion he had offered in page 38 of the paper—about presenting in a single column of figures the essential comparison as to quality of material in all tests, however diverse—had never been intended to be applied to anything but metals, which alone had been treated of in the paper. The results quoted by Professor Unwin as obtained from silk and india-rubber and other materials, and estimated in work done per gramme of weight of the material tested, should at any rate be considered be translated into the corresponding work done per cubic inch of volume, in order to make the comparison apply fairly to the suggestion as offered in the paper. Of course the other qualities could also be obtained from the autograph diagram, namely the first permanent set, the maximum load, and the percentage of extension; the record of these qualities it was by no means desired to eliminate, but on the contrary to ensure the accurate registration of each one of them. For with a practised eye every quality relating to the strength of the material could be realised at a single glance from the configuration and the scale of the record.

Mr. L. Sterne had been hoping Mr. Wicksteed would be able to give some explanation of that drop in the diagram after reaching the elastic limit. In 1876, when Messrs. Hoopes and Townsend of Philadelphia first punched through $1\frac{3}{4}$ inch thickness of cold iron with a $\frac{3}{8}$-inch punch, they obtained diagrams of precisely the same character, which they attributed to the flow of the metal under the continuous load on the punch. By thus introducing the element of time, giving the punch only such a load as it could comfortably sustain, the same laws appeared to hold good both for compression and for tension up to the elastic limits.

The President was sure the members would agree with him that they had had two exceedingly valuable papers, and that the discussion which had followed had been most interesting and instructive. No

(The President.)

one could have designed the machine which had been brought before them by Mr. Wicksteed unless he was a good mathematician, a good physicist, and a good mechanic; and certain it was that to overcome the difficulties presented must also have called for the exercise of no inconsiderable amount of perseverance and pertinacity.

At the same time it should be remembered that, although engineers had here a machine which enabled a test specimen to write its autobiography, there was some danger of their relying rather too much upon its evidence. It had been aptly likened to a policeman, an officer who needed strict supervision by the magistrate. The autographic diagram might tell the whole story of a particular test-piece; but it did not necessarily tell the whole story of the quantity of iron from which that test-piece was selected. A short time ago when visiting Mr. Kirkaldy's testing works he had been shown by him a large heap of test-pieces, which had been sent to him from the country by various inspectors for testing, but which he had declined to test because he considered they were unfair. Either they had little defects in them, or they were cut out of line, or in other ways he considered them not fair samples to test. These considerations should always be borne in mind. Both Mr. Wicksteed and Mr. Bennett had pointed out in their papers how very great a difference there was in the evidence given by test-pieces of different lengths, of different diameters, and of different shapes. All these things had to be taken account of; therefore testing machines of this kind should be valued only up to a certain point. To put the thing in a homely way—too big a sermon ought not to be preached from too little a text.

He had now the pleasure of proposing a vote of thanks to Mr. Wicksteed for his valuable paper; and also to Mr. Herbert B. S. Bennett, Mr. Henry S. Bennett, and Mr. Charles S. Bennett, sons of the late Mr. Peter D. Bennett, for their kindness in completing their father's posthumous paper and allowing it to be read at this meeting.

DESCRIPTION OF A HYDRAULIC BUFFER-STOP FOR RAILWAYS.

By Mr. ALFRED A. LANGLEY, of Derby.

The object of the writer in designing this contrivance has been to prevent the severe accidents arising from trains over-running terminal stations or dead ends on railways. Hitherto, when through failure of brakes, defect of locomotive, or bad judgment in not reducing speed, a train has unfortunately dashed into an ordinary dead buffer-stop, the result has frequently been disastrous, resulting in the telescoping and breaking up of the carriages. This danger arises not so much from the actual concussion of the engine against the buffer, as from the recoil consequent upon a heavy moving body encountering a fixed dead obstruction; the ordinary buffer-stop, as is well known, is usually constructed with a view to the greatest possible rigidity.

The Hydraulic Buffer-Stop, both in principle and in effect, is diametrically opposed to the ordinary plan. Its chief advantages are:—

1st. Absence of recoil after collision.

2nd. Continuous uniform resistance for bringing a train to rest.

3rd. Absence of shock or breakage either in train or in buffer.

The construction is shown in Figs. 1, 2, and 3, Plate 12. The chief feature is the application of hydraulic resistance by the use of pistons working in horizontal cylinders filled with water and fixed in line with the buffers of the rolling stock.

The cylinders, as shown in the sectional plan, Fig. 6, Plate 13, are 4 ft. 7½ ins. long, cast with a flange on each end, and bored out to 12 inches diameter with 2½ inches thickness of metal. Covers are bolted to the flanges, and each is fitted with a hydraulic

gland for the passage of the piston-rod, which goes through both ends of the cylinder. The packing consists of a hydraulic cup-leather, inserted in the stuffing-box and fitting the piston-rod tightly. The rod is of solid steel, $3\frac{3}{4}$ inches diameter, and 13 ft. 1 in. long over all. An india-rubber ring 1 inch thick is fixed round the rod at JJ on each side of the piston, to form a cushion between the piston and the cylinder ends.

The piston is turned to an easy fit, the clearance space between its circumference and that of the cylinder being equal to an area of 0·38 square inch. In addition to this constant space, a gradually diminishing area of passage has been contrived, whereby a uniform resistance is maintained throughout the stroke. As shown in the longitudinal section of the cylinder, Fig. 6, Plate 13, a wrought-iron strip R, 3 inches wide, is fastened by stud screws along each inner side of the cylinder, projecting $\frac{9}{16}$ inch into the cylinder at the beginning of the stroke and tapering up to $1\frac{1}{16}$ inch at the rear end. A corresponding slot $1\frac{1}{16}$ inch deep is cut out in each side of the piston.

The resistance offered by the water to the movement of the piston depends on two things, namely the velocity of the movement, and the amount of clearance space between the piston and cylinder. The velocity of movement will always be greatest at the commencement of the stroke; but as the piston is forced backwards the clear space between the tapering strips and the slots in the piston becomes less and less, as shown by the black areas in the four transverse sections A, B, C, D, Fig. 5, Plate 13: so that, notwithstanding the diminishing speed, an equal amount of resistance is maintained until the train is brought to rest. To ensure keeping the cylinders constantly filled with water, a supply pipe P is fixed to the front end of each, Fig. 3.

It has been proved by experiment that a 4-ft. stroke is amply sufficient for all practical purposes; a train going at least eight miles an hour is brought to a stand before the stroke is completed, without any damage whatever either to train or to buffer. The interiors of the first set of cylinders tried were bored taper, and the size of the pistons was arranged so as to give a uniform resistance, as in the case of the tapering strips. The tapering

cylinders however were found somewhat inconvenient to manufacture, and were accordingly replaced by the strips.

The piston-rods in their normal position, ready to receive a train, project 6 ft. from the face of the cylinders, as shown in Figs. 1 and 3, Plate 12. This allows 2 ft. for the construction of a fixed stop T, to prevent any possible injury from undue pressure on the cylinder ends at the completion of stroke. The stop consists of four permanent-way rails fixed transversely across the front end of the cylinders, two over and two under the piston-rods, and connected together by a loose guide through which the rod passes. A buffer-head is fixed on the extremity of each piston-rod, to correspond with the buffers of the rolling stock.

After an impact has taken place, the pistons are drawn forwards again into their original position by the action of counterweights W suspended in a pit under the fore part of the buffer. A $\frac{3}{4}$-inch chain from the weight passes over a fixed pulley under the cylinder, and is shackled to a cross-head H upon the back end of the piston-rod. The cross-head has a wheel on each side, Fig. 6, running along a guide path. The counterweights are cast-iron discs, as shown in Fig. 4, with a packing of felt F between each, and a seating S of india-rubber between the bottom weight and the holding bolt, to take the first shock of the strain upon the chain when the buffer is struck by a train. Several schemes were tried for bringing the pistons forwards again after impact. Strong india-rubber bands fastened to the cylinder and to the end of the piston-rod proved very troublesome, as it was difficult to obtain bands of the required elasticity and at the same time thoroughly reliable. A plan was also successfully carried out for returning the pistons by the pressure of a head of water acting behind them. In this case the rod does not pass through the rear of the cylinder; and the water displaced by the insertion of the rod at the front end is forced into a tank of sufficient height to drive the piston forwards in its return stroke. The plan of counterweights however, as shown in Fig. 1, has proved the best for general use.

The body of the buffer-stop consists of a block of Portland cement concrete, Figs. 1 and 2, Plate 12. Timbers are let in the top, to which the cylinders are secured by an iron clamp passing over each

cylinder end, Figs. 1 to 3. It was found best to put the counterweight pit in front of the stop, Fig. 1, where it can thus at any time be easily inspected. The top of the buffer is boarded over, and if necessary may be utilised for offices, refreshment rooms, &c. No difficulty is experienced from freezing of water when under a roof; but to prevent all possibility of damage by frost, a small gas jet may be kept burning under the cylinders during cold weather.

At first the buffers were designed with a cross-head or beam connecting the two buffer-heads; but this was soon abandoned through fear of the buffers being pressed in unequally. Air was also thought of as a resisting medium, in place of water. In a case of this sort however the use of air is to be avoided, on account of the risk of explosion, which would, as in the bursting of boilers, cause the parts to fly, and might prove dangerous.

The risk of accidents from trains running into dead ends is of course daily increasing with the extension of powerful brakes. On most railways it is a rule that drivers are not to rely on the brakes for coming into stations; but it is in the nature of things that they will do so, and it frequently happens that a driver does run into a station at a higher speed than he intended or expected. In such cases the use of these buffers will at any rate vastly diminish the liability to serious accidents, as frequent trials have proved that they afford resistance sufficient to stop a train at eight miles an hour without shock or any damage whatever. The Liverpool Street and Fenchurch Street stations, London, on the Great Eastern Railway, are furnished with these stops, which continue to answer perfectly. At Fenchurch Street station a refreshment room is erected immediately over the cylinders, and a train running into the stop produces no shock whatever in the room.

The first cost of a hydraulic buffer-stop complete, with a 4-ft. stroke, is about £150. The cost of maintenance is very small indeed compared with that of maintaining the ordinary stops at terminal stations, which are constantly undergoing renewals or repairs. The hydraulic buffer-stop, as shown in the drawings, takes up much less room in a station than the ordinary dead buffers: the latter would

occupy a length of 10 or 14 feet, shortening the line of way by this amount of valuable space; but the hydraulic stops, if fixed under a roof, require a space of only about 2 feet length out of the available running line, the cylinders being fixed under the building. It would not be safe to fix a dead buffer under or close to a building, as the shock of a train would damage the latter.

The length of stroke is an important consideration; and several trials had to be made before the stroke of 4 feet was adopted at Liverpool Street and Fenchurch Street stations, as being about the right length. When a moving body is opposed by a retarding force properly applied, it can be stopped in a comparatively short distance, as in catching a cricket-ball, by which the hands would be hurt if they were not quickly withdrawn the moment the ball touched them. A spring does just what it ought not to do, offering very little resistance at first, when most required, and a great deal of resistance at last, when least required; this causes a recoil almost as violent as the first blow. If a buffer-stop were required to receive trains running at a speed not exceeding four miles an hour, a stroke of 2 feet would probably be sufficient to prevent any violent shock. This would meet the case of ordinary shunting, and would of course cost much less than a buffer-stop fixed with a 4-ft. stroke; but in the event of a train over-running, or the brakes failing to act, it might not be sufficient.

The theory of the hydraulic buffer-stop appears to be that its resistance varies approximately as the square of the train's velocity, while the train's moving force varies also approximately as the square of its velocity: so that the piston-rods will be pushed inwards through about the same actual length of stroke, whatever be the velocity. The number of units of work accumulated in a train moving with a given velocity can be easily estimated; but to calculate the effect upon the hydraulic buffer-stop at various parts of the stroke is more difficult, because in the case of a train of say ten carriages there are more than forty springs belonging to the vehicles, which come into play when the train runs into the buffer-stop, and cause an alteration in the mode in which the hydraulic

buffer has to meet the work; and this is provided for by the taper strips being properly shaped in relation to the slots in the pistons. The total units of work in the train must of course be absorbed by the hydraulic buffer-stop within the range of its stroke; and it is probably to a large extent the action of the train springs which causes the short stroke of only two or four feet to be so effective.

The hydraulic buffer-stops with 4-ft. stroke at Liverpool Street and Fenchurch Street stations were fixed about four years ago, and were the first hydraulic buffer-stops ever put up, so far as the writer is aware. Hydraulic buffer-stops with 2-ft. stroke have recently been fixed at the new Exchange Station of the London and North Western Railway in Manchester.

Discussion.

Mr. Langley mentioned that the chairman of the Great Eastern Railway, Mr. Parkes, had been the first to speak to him about taking some steps for preventing the accidents and damage which had several times occurred from trains running into fixed stops. He had accordingly devised the hydraulic buffer-stop now described, of which a great number of trials had been made; and he believed so far the plan had proved satisfactory. As regarded the calculation of the resistance offered by the stop, the number of units of work to be overcome in stopping an engine and train of say 150 tons total weight, running into the stop at a speed of eight miles an hour or 12 feet per second, would be $150 \times 12^2 \div 64{\cdot}4 = 336$ foot-tons nearly, which divided by the 4-ft. length of stroke gave 84 tons total pressure against the stop; and 84 tons on two cylinders of 12 inches diameter gave a pressure of about 832 lbs. per square inch.

Having recorded by a gauge as nearly as he could the actual pressures in the stops already at work, he had found them to be somewhere about that amount, ranging from 800 to 1000 lbs. per square inch. He understood from Messrs. Ransomes and Rapier, who had taken the matter up, that they were now making for the overhead station at Ludgate Hill a hydraulic stop with an 8-ft. stroke for Messrs. Brunel and Barry, by whom it was calculated that it would resist a train running at twenty miles an hour.

Mr. Beauchamp Tower asked whether the remarkably interesting property mentioned as pertaining to the hydraulic buffer-stop—namely that the piston always made the same length of stroke, no matter what was the speed of the train—had been proved in practice. Although it was in accordance with theory, yet there was the constant friction of the stuffing-boxes and pistons, as well as other friction, which would tend to prevent it from holding good exactly in practice.

Mr. Benjamin A. Dobson mentioned that he had seen the hydraulic buffer-stops at the Exchange Station, Manchester; and from what information he could obtain he understood that their action was satisfactory. But when he saw them they had a train of empty carriages against them, and they were almost closed up, with only a small amount of piston-rod left outside; so that he had unfortunately been unable to see them in action. The question therefore occurred to him to ask, what provision was made to prevent a train or a carriage from being left against the stop and keeping the piston-rods closed up: because in that case there would be no hydraulic resistance to the impact of a second train which might happen to run into the first.

Mr. Joseph Tomlinson said he had seen the hydraulic stops on the Great Eastern Railway, but he had never had the good fortune to see them in operation. The plan seemed to him to have in it the element of what was required. The ordinary fixed buffer-stops with a resistance of about 6 tons were simply a delusion and a snare,

(Mr. Joseph Tomlinson.)

because running into them with an ordinary locomotive was like running into a dead wall, and it was utterly impossible they could stand against any speed worth naming. Having the power to resist a train at eight miles an hour with safety, the hydraulic buffer-stops fulfilled pretty nearly all that was wanted. In his own experience of accidents from trains running into the ordinary fixed stops, nothing like a speed of eight miles an hour had been attained; though of course there had been isolated cases of speed high enough to go clean through stops and buildings too; but nothing would provide against such a contingency as this except some gigantic mass of solid material, which might be a sure stop, but not a very agreeable one. The hydraulic buffer-stop could not be expensive to maintain. But the ordinary fixed stops constructed of posts put into the ground, if they were hit even at two miles an hour by a train of 200 tons, had always to be replaced immediately afterwards. In these and other respects he considered the hydraulic stops were a great improvement on those hitherto in use.

With reference to Mr. Dobson's remark about the pistons remaining closed up when a train was left standing against them, he did not see how that could well be avoided, because the only means of drawing the pistons forward again was by removing the obstruction so as to let the counterweights bring them forward again into their original position. If the stop was once forced home, there it must stay until whatever had struck it came away from it; the same was the case with all buffer-stops. If, while a train was left standing against the stop, anything ran into the other end of the train, the buffer-springs of the carriages would take up the blow, and the buffer-stop would feel the blow in a small degree only.

Mr. E. H. CARBUTT, M.P., was very glad the subject of this hydraulic buffer-stop had been brought before the Institution, because, owing to the demands of the public for increased brake-power on trains, engine-drivers were now accustomed to run at full speed up to the entrance of the station before beginning to pull up. Sometimes, after having taken on at a junction two or three carriages that were not fitted with self-acting brakes, a driver had

run into a terminal station, forgetting that the brake was not self-acting over the whole of the train, and had run in at an excessive speed. Very recently he had seen a case of that sort happen, where a dead buffer-stop had been moved bodily forwards through a distance of 16 feet. If the hydraulic stop had been there, no doubt the passengers would not have been so much shaken, though perhaps the buffer-stop might have been moved a little. By the hydraulic stop he thought an engine with a brake van and one or two carriages would at the same high speed have been brought to a standstill without doing any damage either to the rolling-stock or to the passengers. It was a very sensible plan for overcoming the present difficulties; and as he was sure the public would insist more and more upon having brake-power sufficient for every class of train, it would therefore be very useful to put up these hydraulic stops in every terminal station.

Mr. Benjamin Walker mentioned that a similar hydraulic buffer had been practically in use for many years for controlling guns. Fourteen or fifteen years ago the late Sir William Siemens had been consulted by the British government as to the best means of taking up the recoil of a gun, and had suggested that water would be a good medium, though he did not then make up his mind how that medium was to be used; and to the ingenuity of Mr. Butter,* the manager of the gun-carriage department at Woolwich, the credit was due of having carried out practically the notion of Sir William Siemens. In the first instance a small hole had been made through the hydraulic piston; and ultimately a pair of tapering bars were fixed all along the inside of the cylinder, with corresponding slots in the circumference of the piston. The recoil of the gun could be regulated at pleasure; if it was found that the gun went back with too great force, and endangered the stops on the carriage, the resistance of the water passing through the holes could be increased by partially closing them. The hydraulic buffer had also been used

* See Proceedings of the Institution of Civil Engineers, 1881, vol. lxvii., page 122.

(Mr. Benjamin Walker.)
by Mr. Vavasseur for the same purpose of controlling guns on his gun-carriage. The contrivance was indeed very similar to the cataract used for so many years past for controlling the speed of the Cornish engine. A similar plan had also been applied over and over again to control a steam-engine, by using a small pump attached to the engine, so that if the engine increased in speed, the volume of water pumped was increased, and closed the throttle-valve correspondingly. In the hydraulic buffer-stop the application of the same principle of water resistance for stopping railway trains constituted in his opinion a very valuable invention.

Sir JAMES N. DOUGLASS had seen the hydraulic buffer-stop on its completion at Fenchurch Street station; and being constantly very near that spot he had had frequent opportunities of seeing the buffer in action. It happened that at the time when he first saw it he had just been witnessing some experiments with 80-ton guns at Dover, where the same principle was rightly applied for neutralising the force of the recoil; and its perfect success for that purpose had satisfied him that it would prove equally satisfactory as now applied by the author in the form of a railway buffer-stop. No doubt all contrivances when they came to be analysed would be found to be old in some part or other; but great credit was due for so valuable an application as had here been made of the familiar principle of hydraulic resistance, which the author had succeeded in putting into a practical shape for stopping trains, as was done with such perfect success at Fenchurch Street station.

Professor ROBERT H. SMITH observed that the counterweight had a seating of india-rubber interposed between the head of the holding bolt and the bottom of the weight, in order to prevent the chain from being damaged by the sudden shock upon it at the beginning of the motion. This expedient must become still more important when it was proposed to provide for the stoppage of trains running at anything like twenty miles an hour. It therefore occurred to him to suggest that the fixed pulley over which the chain from the counterweight passed, and from which it was seen that the chain

sloped upwards to the shackle on the cross-head at only a slight inclination from the horizontal, should be shifted further back towards the cross-head, so that at the beginning of the motion the chain should descend from the cross-head to the pulley in a nearly vertical line. There would then be hardly any stress at all thrown upon the chain at the first shock; and the stress upon the chain would increase gradually as the piston was driven further in.

Mr. L. Sterne had no doubt such an ingenious arrangement as the author's would not have been designed and erected if there had not been a necessity for it. Having himself endeavoured to make buffer-stops with a considerable range of stroke, he had found it difficult to do so, because the amount of the overhanging weight was always an increasing objection to the increase of the projecting length. Nearly eleven years ago he had made some for the Glasgow and South Western Railway, which were fixed in St. Enoch's station, Glasgow, and had answered very well; but considerable judgment was nevertheless required in running into the station, so as not to over-run and come in contact too violently. Up to an 18-inch stroke he considered it safe to go; but beyond that it was difficult to construct anything like an ordinary buffer without having too heavy an overhanging weight. Behind the buffer-stops were a book-stall and a refreshment stall, neither of which had yet been disturbed by violent shocks. The resistance was given by an india-rubber pneumatic spring, very strongly constructed. It was true that, as pointed out in the paper, it gave very little resistance at first, and an increasing resistance afterwards; but the carriage springs assisted so much, since each spring in each carriage was compressed to a certain extent before the stop springs had really yielded much, that by the time they had done so the shock had become considerably lessened. The design described in the paper he considered a remarkably ingenious one; and its application proved it to be effective, and to supply a want in a mechanical and efficient manner.

Mr. J. Fortescue Flannery observed that the absence of recoil in the hydraulic buffer-stop, which prevented its resuming its original

(Mr. J. Fortescue Flannery.)

forward position so long as a train which had run into it was left standing against it, was inherent to this plan. As remarked in page 109 of the paper, "a spring does just what it ought not to do, offering very little resistance at first, when most required, and a great deal of resistance at last, when least required; this causes a recoil almost as violent as the first blow." Unless therefore there was a continual storing up and increase of power towards the end of the stroke of the buffer, there would be no power to overcome the inertia and friction of a train left standing against the stop, and to push it off again from the closed up stop. In practice he thought it would not be found to be a real objection that the buffers were useful only when the line was empty; for it was very seldom that a platform was so long that a second train was run up at a speed to cause damage to a train already standing there. That was of course sometimes the case, but it was very exceptional.

With reference to the remark that this plan was in some degree similar to that suggested by Sir William Siemens for absorbing the recoil of guns, he thought the present was simply another instance of hydraulic power being usefully applied to various and almost unexpected purposes; and the very successful and ingenious arrangement described in the paper showed that the use of hydraulic pressure had yet to be much extended before the limits of its application were reached.

Mr. HORACE WILMER said that it had been his business to fix most of the hydraulic buffer-stops on the Great Eastern Railway, and it had since been his duty to maintain them; and he had much pleasure in bearing testimony to their efficiency. They had been designed in the interest not only of the railways, but also of the travelling public at large. Up to the present time the stops on the Great Eastern Railway had been fortunate enough not to have been tested by any trains running into them accidentally. The only tests which they had undergone, so far as he knew, had been experimental tests, in which trains had been run into them at the rate of from eight to twelve miles an hour; and the pressure of water in the cylinders had been observed by means of a pressure-gauge. On the last occasion of fixing

a set of buffer-stops on that railway they were tested experimentally with an engine running into them at that speed; and the pressure at the moment when the engine was brought to rest was observed to be about 800 lbs. per square inch. There was only one danger that he knew of with appliances of this sort which were very rarely used, and that was lest they might not be kept in a proper state of efficiency. It was therefore the practice at Fenchurch Street station to arrange for the drivers to push the hydraulic pistons home each morning, on first coming into the particular platform line where these buffers were fixed: after the engine was detached from the train it had brought in, and the train had left the station, the engine worked up to the buffers and drove the pistons in up to the end of their stroke; and then as the engine went away the pistons came forwards again to their normal position. With reference to their absence of recoil so long as a train was left standing against them, it would be borne in mind that these buffer-stops were not intended to minimise a collision between two trains, but simply to absorb the excessive velocity of a train over-running a station.

Mr. Henry Robinson considered it one of the merits of the present paper that it described a particular appliance devised for a special purpose. It was true that hydraulic power had been used for other similar purposes, such as taking up the recoil of guns; but it was surely a merit in any mechanical paper that it did not travel very far into history. There was a well-known arrangement for controlling the steam starting-gear in marine engines, by means of oil or water in a cylinder with a perforated piston, or with a passage communicating from one end of the cylinder to the other; but it would have occupied unnecessary time if this and other similar arrangements had been referred to in the paper; and he considered their omission was an advantage rather than the reverse.

Mr. Langley, replying to Mr. Tower's question whether the same length of stroke was always taken up in stopping a train, said that in this matter practice was found to agree pretty nearly with

(Mr. Langley.)
theory. If a train came in slowly, the pistons were nevertheless driven in about as nearly home as when a train came in quickly. A very moderate force pushed the pistons in slowly; but if a train came in with considerable velocity, it met with a correspondingly greater resistance.

In regard to the stops which Mr. Dobson had found remaining closed up at the Exchange Station in Manchester, of course a train of carriages left standing against the hydraulic buffer-stop would keep it closed up. But, as had been already remarked, it was not usual for two trains to get into the same siding; and if there were a second train running into the first, the carriage springs would offer a considerable amount of resistance, and the blow on the buffer-stop would not be of the same serious character as if the train had run into a solid stop.

In running into the stops experimentally, it had not been easy to record the speed, which he believed had been as much as ten miles an hour, though it had been put at eight in the paper so as to be on the safe side. The only means he had had of testing the speed had been by running alongside the engine with his hand on the rail; and it was as much as he could do to keep up with the engine till it struck the buffer-stop. The speed would certainly be eight miles an hour, for he was running pretty smartly.

Running into fixed buffer-stops was not a rare occurrence, and they had to be reconstructed and put right again after they had been run into. The fixed buffer-stop mentioned by Mr. Carbutt was probably one at Leeds, which had been moved bodily through 16 ft. by a train running into it. It was quite true that since he had designed the first of these hydraulic buffers he had become aware of its similarity to the hydraulic apparatus employed for absorbing the recoil of big guns; the principle was the same in both cases.

With regard to the india-rubber seating between the counter-weight and the chain bolt, a $\frac{1}{2}$-inch chain had at first been tried by itself, without any india-rubber cushion at the bottom of the weight. When first the buffers were struck, the chain snapped; but there was no accident, and the pistons were simply not drawn forwards again into their normal position. But a $\frac{3}{4}$-inch chain he

thought was strong enough not to break under a sudden snatch at a speed of eight or ten miles an hour, particularly with the addition of the india-rubber cushion.

The President gathered from the drawings that the slots through the pistons were fitted with gauge-plates for regulating the size of the orifices.

Mr. Langley thanked the President for calling attention to the gauge-plates, which were shown in Figs. 5 and 6, Plate 13. They had been provided for the purpose of ascertaining by experiment the proper size of the openings through the pistons, because he had not considered it enough to determine the area of the apertures by calculation before actual trial. By means of the adjusting screws fixing the gauge-plates they had been shifted until the size of the orifices was finally found to suit the requirements.

The President was sure that, even though a buffer-stop might seem to many an appliance of minor importance, yet after the discussion which had taken place the members would all agree it might become a very important affair, if they happened to be passengers in a train running into it. The necessity for efficient buffer-stops had increased greatly with the use of modern pneumatic brakes. Without these, passenger traffic could not be worked with the safety and regularity which had now been attained. In fact, next in importance to the power to set a train in motion was the power to keep it under control, and to stop it when necessary. But with the very powerful brakes now used came the danger that occasionally they might fail, either through something getting out of order or through miscalculation on the part of the engine-driver; and the train might run into a buffer-stop. It was no longer the practice in this country to shut off the steam long before reaching a station, and then creep slowly into it, as was still done on some continental lines; but trains ran almost at full speed right into the stations. The paper which had been discussed was a very important one; and when it was remembered that the cost of one of these appliances

(The President.)

was only £150, it seemed mistaken economy not to have them at all terminal stations. There was no doubt, as had been pointed out, that the same principle had for some time past been adopted in the case of gun-carriages. In fact in the case-mated turrets on board war-ships it would be quite impossible to work heavy guns without some such arrangement. But as far as he knew the application of the principle to railway buffer-stops was new and original; and he therefore thought that the author deserved great credit for the successful manner in which he had carried it out. He had much pleasure in proposing a vote of thanks to Mr. Langley for his excellent paper.

MEMOIRS.

William Hopper was born at Penicuick near Edinburgh on 22nd June 1816, and at the age of fifteen was apprenticed as a millwright to Mr. Trotter, Broomhouse Paper Mills, Berwickshire, serving his apprenticeship both there and at Kelso. In 1838 he went to Manchester, and served with Sir William Fairbairn, Messrs. Wren and Bennett, and Messrs. Gordon and Davies. In 1842 he went to Mr. Benjamin Hick, Bolton, by whom he was sent in June 1843 to Russia, where he undertook first the erection of the gearing in a cotton-mill then being built near St. Petersburg by Messrs. Egerton Hubbard and Co. He next went to Moscow, and performed the same service at Mazourin's mill, and subsequently at Lepeshtern's. In 1847, on the completion of the latter mill, he entered into partnership with Mr. Wrigley, and started a foundry in connection with a small weaving-mill. In 1867 he acquired the whole concern, and thenceforth carried it on prosperously on his own account, assisted latterly by his sons. The works were gradually extended until at one time they employed 450 men. His death took place in Moscow on 23rd April 1885, at the age of sixty-eight, after a long illness consequent upon a chill caught in travelling. He became a Member of the Institution in 1867.

Moraston Ormerod Norris, son of Mr. J. E. Norris, solicitor, was born in Halifax, Yorkshire, on 5th December 1857; and after being educated at Clifton College, entered the Royal Indian Engineering College, Cooper's Hill, in September 1877, where he went through the three years' course. He was then sent for a year to the locomotive engine works of Messrs. Dübs, Glasgow; and then to the Great Western Railway works at Swindon. In October 1882 he went to Madras, in the service of the Public Works Department,

to the irrigation works in the Godavery district; and after a few months was transferred at his own request to the Ajmeer and Malwa Railway. Being taken ill there with severe paralysis in July 1884, he returned home; and died in Paris on 7th April 1885, at the age of twenty-seven. He became a Graduate of the Institution in 1881.

Robert Charles Ransome, chairman of Messrs. Ransomes Sims and Jefferies, Orwell Works, Ipswich, was born in Ipswich on 1st June 1830, being the grandson of Mr. Robert Ransome, by whom the business had been founded in 1789. He was educated at the Friends' schools at Hitchin and York. At the age of sixteen he entered the works, and after passing through the shops was entrusted before the age of twenty-one with the entire responsibility of executing in Durham and Derbyshire important contracts for railway chairs, which were made on the spot. When twenty-seven years of age he joined his father, Mr. Robert Ransome, and Mr. Allen Ransome, and Mr. Sims, as a partner in the firm. He early devoted himself to the development of the business commercially, and especially abroad; he travelled extensively through Europe, and visited Egypt, and in later years the Australian colonies and New Zealand, and on two occasions the United States. In connection with the late Mr. John Fowler, of Leeds, he took an important part in the manufacture and introduction of the steam plough. To the introduction of the portable steam-engine and steam thrashing-machine he gave much attention, his firm having been one of the earliest producers of portable engines; whilst the first steam thrashing-machine and the first agricultural locomotive were exhibited by them at the Royal Agricultural Society's shows at Liverpool in 1841 and Bristol in 1842 respectively. Ever since 1785, when a method of tempering cast-iron plough-shares had been introduced by Robert Ransome, of Norwich, followed in 1803 by his celebrated chilled plough-share, the improvement of the plough has much occupied the attention of the firm, by whom it has been brought to a high state of perfection. They have also been large producers of agricultural machinery and implements, as well as of an extensive variety of general engineering work. Mr. Ransome was

for many years associated in business with the late Mr. John Head, and his brother, Mr. James Edward Ransome, and Mr. John Robert Jefferies. He devoted much attention to the education question, feeling the necessity of more highly cultivated intelligence in our artisans, for enabling England to keep her place in the world. He was chairman of the Ipswich school board for twelve years, from its commencement in 1871; and a governor of the Albert Memorial College, Framlingham. He was elected mayor of Ipswich when thirty-seven years of age; and was a member of the council of the Royal Agricultural Society of England, and a magistrate for Suffolk as well as for Ipswich, and an alderman of the borough. His death occurred on Friday, 5th March 1886, at the age of fifty-five, from aneurism of the heart, from which he had suffered for many months. He became a Member of the Institution in 1869.

Albert Harrison Turner was born at Kensington on 4th March 1857. After being educated at Sevenoaks grammar school he spent nearly two years at the Crystal Palace School of Practical Engineering, passing through the mechanical course and the surveying department. In 1875 he entered the employment of Messrs. Christopher James and Co., London and South Wales, iron merchants and colliery proprietors, with whom he remained for a few years. In February 1880 he was engaged by Messrs. F. and A. Swanzy, London, as engineer and surveyor of their gold mine at Wassaw on the Gold Coast of West Africa; and in July 1882 was appointed manager, engineer, and reduction officer of the Wassaw Gold-Coast Mining Co. He was one of the pioneers of the West African gold mining industry, in connection with which he carried out the erection of the machinery, engines, boilers, and stamp-heads, the work being done principally by natives who had to be taught by himself how to use the necessary carpenters', fitters', and smiths' tools. His death took place at Wassaw on 5th December 1885, at the age of twenty-eight, after a few days' illness from jaundice and fever. He became a Member of the Institution in 1884.

AUTOGRAPHIC TEST-RECORDER.

Plate 1.

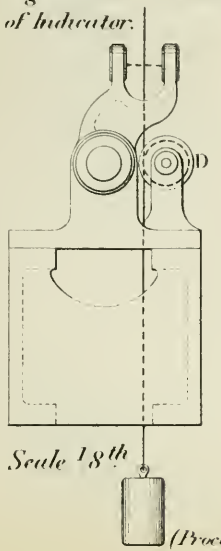


Fig 2. *End Elevation of Indicator.*

Scale 1/8th

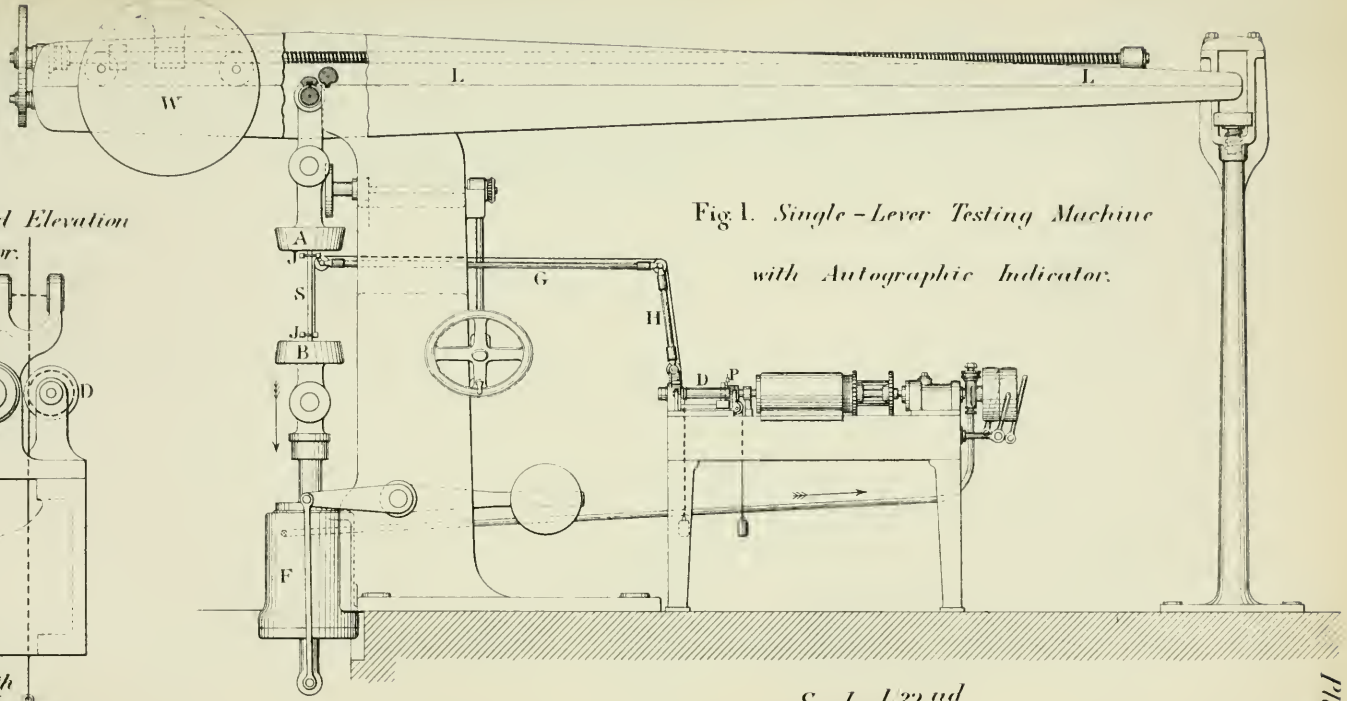


Fig 1. *Single-Lever Testing Machine with Autographic Indicator.*

Scale 1/32nd

(Proceedings Inst. M.E. 1886.)

Ins. 12 6 0 1 2 3 4 5 6 7 8 9 10 Feet.

Plate 1

AUTOGRAPHIC TEST-RECORDER.

Autographic Indicator.

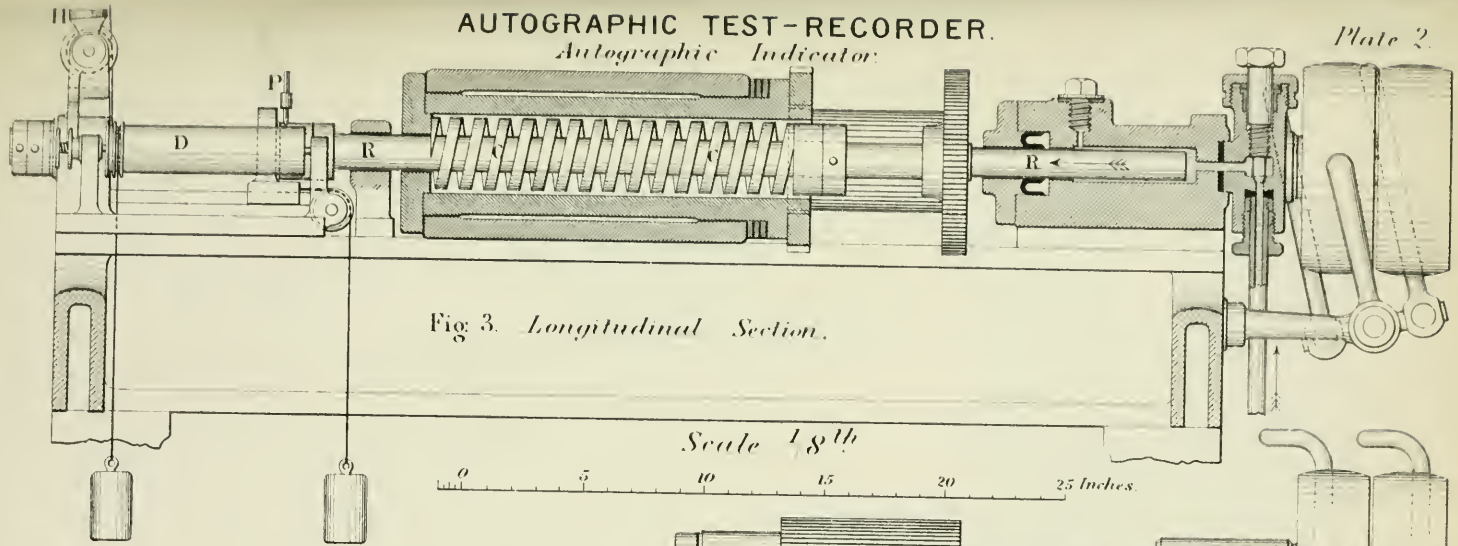


Fig. 3. *Longitudinal Section.*

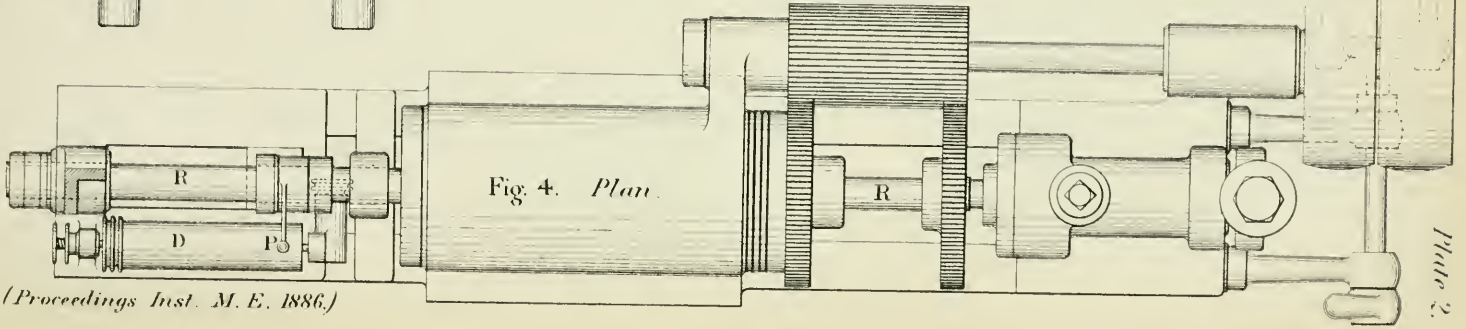


Fig. 4. *Plan.*

(Proceedings Inst. M. E. 1886.)

Plate 2.

AUTOGRAPHIC TEST-RECORDER.

Fig. 5. *End Elevation.*

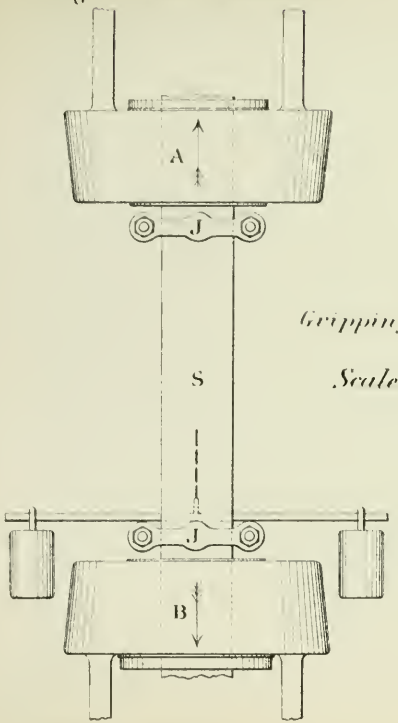
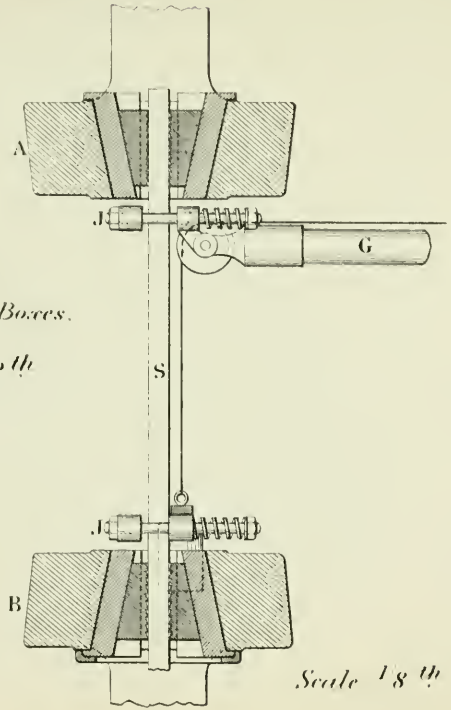


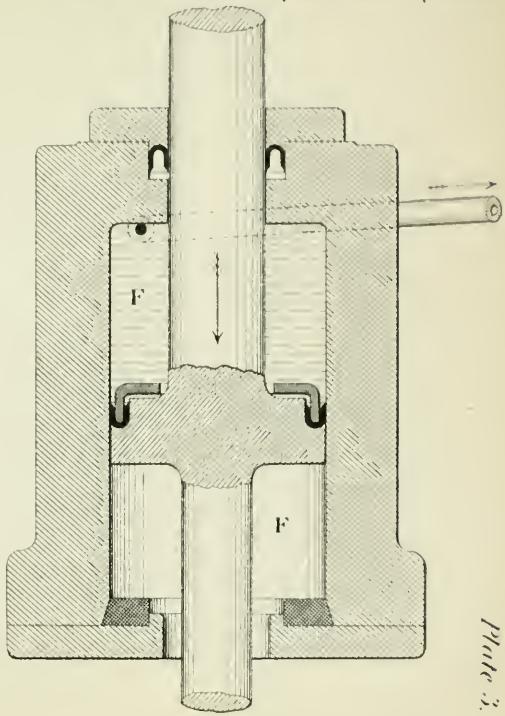
Fig 6. *Section.*



Gripping Boxes.

Scale 1/8th

Fig 7. *Section of Main Hydraulic Cylinder*



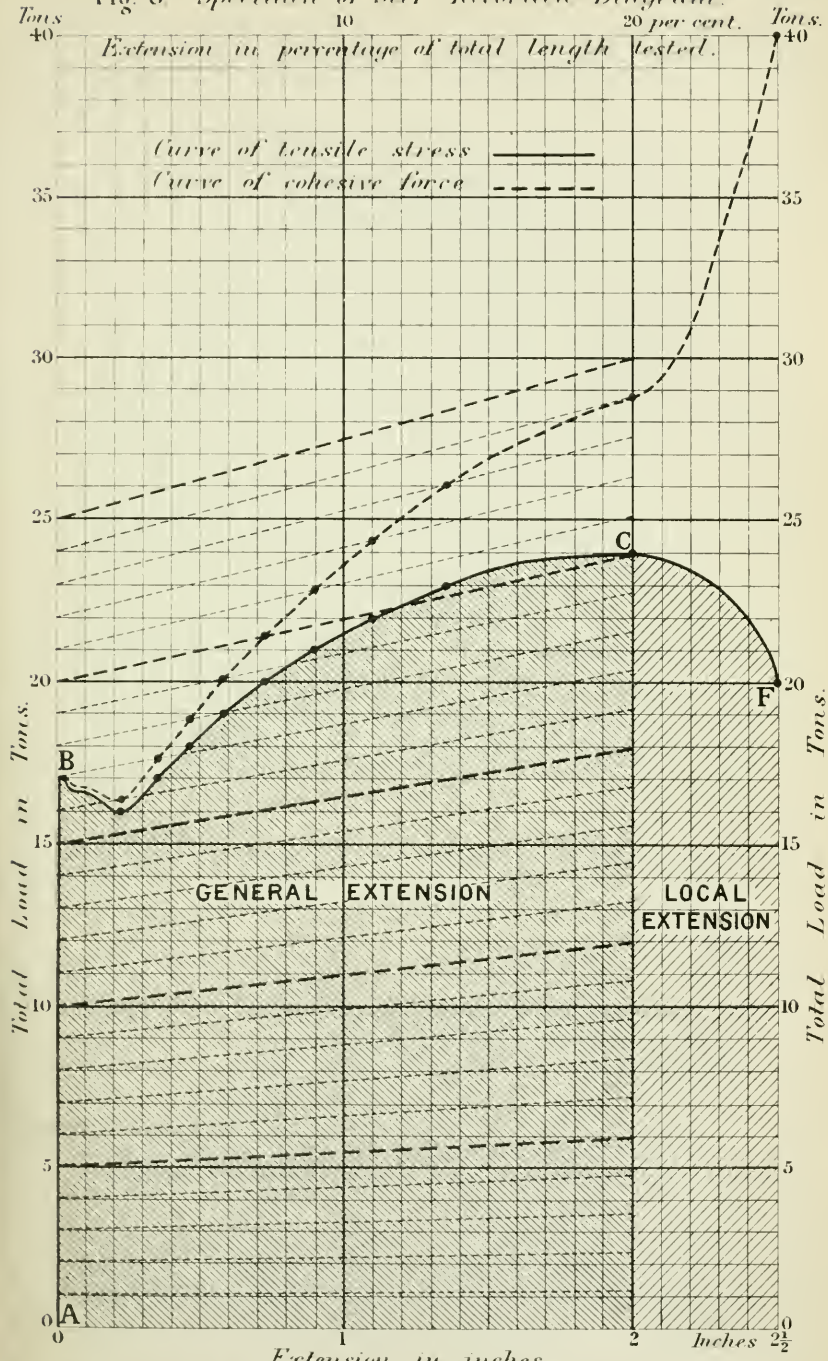
Scale 1/8 th

0 5 10 15 20 25 Inches.

(Proceedings Inst M.E. 1886.)

Plate 3.

Fig. 8. *Specimen of Self-Recorded Diagram.*



(Proceedings Inst. M.E. 1886.) *Scale 1½ times full size.*

Copies of Self-Recorded Diagrams, full size.

Fig. 9. *Mild Steel Bar turned to 1 sq. inch.*
Maximum Load 24·12 *tons.* *Elongation* 2·98 *ins. in* 10 *ins.*
Mechanical Work of rupture 66 *inch-tons.*

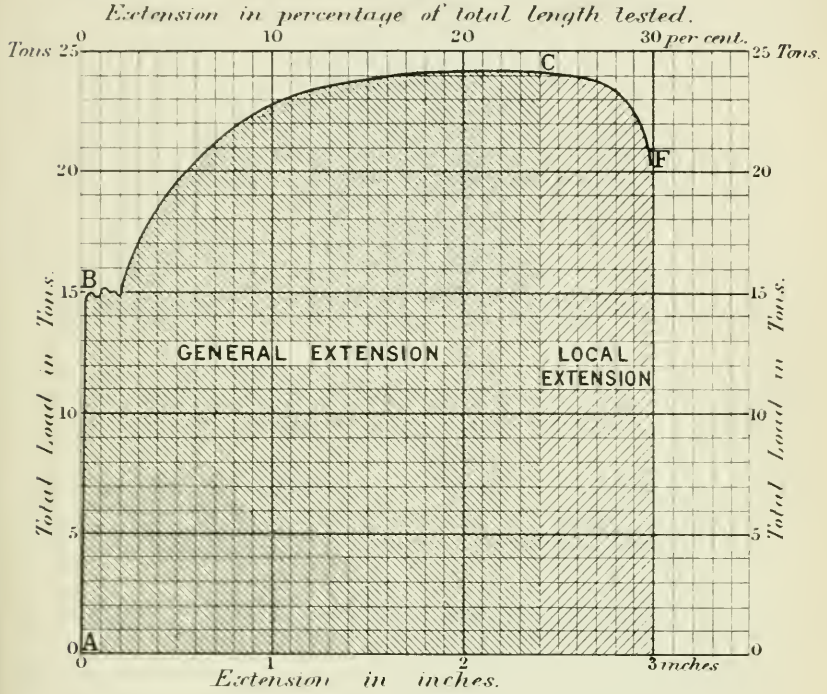
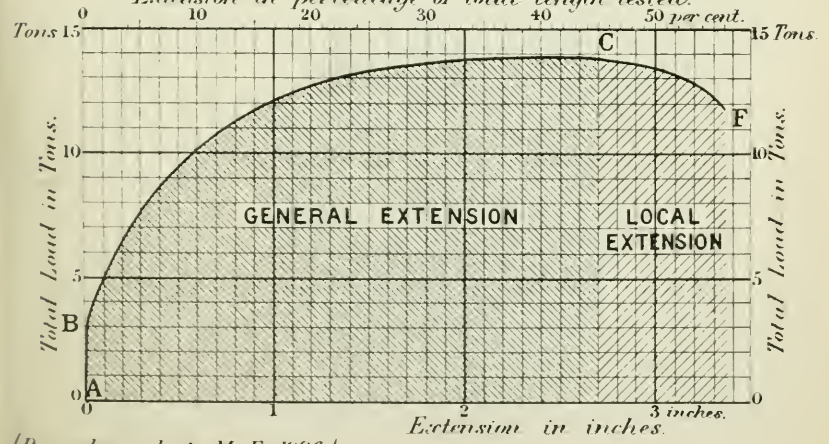


Fig. 10. *Copper Bar turned to 1 sq. inch.*
Maximum Load 13·80 *tons.* *Elongation* 3·36 *ins. in* 6 *ins.*
Mechanical Work of rupture 41 *inch-tons.*



(Proceedings Inst. M. E. 1886.)

Copies of Self-Recorded Diagrams, full size.

Fig 11.

Brass Bar turned to 1 sq. inch.

Maximum Load 14·14 *Tons.*

Elongation 1·05 *inch in* 10 *ins.*

Mechanical Work of rupture 13 *inch-tons.*

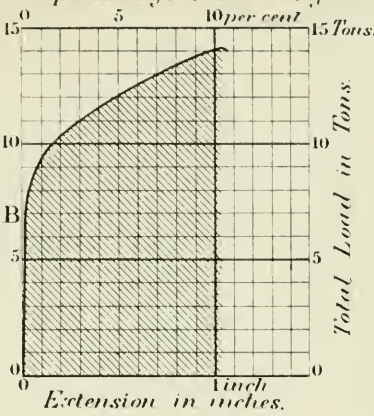


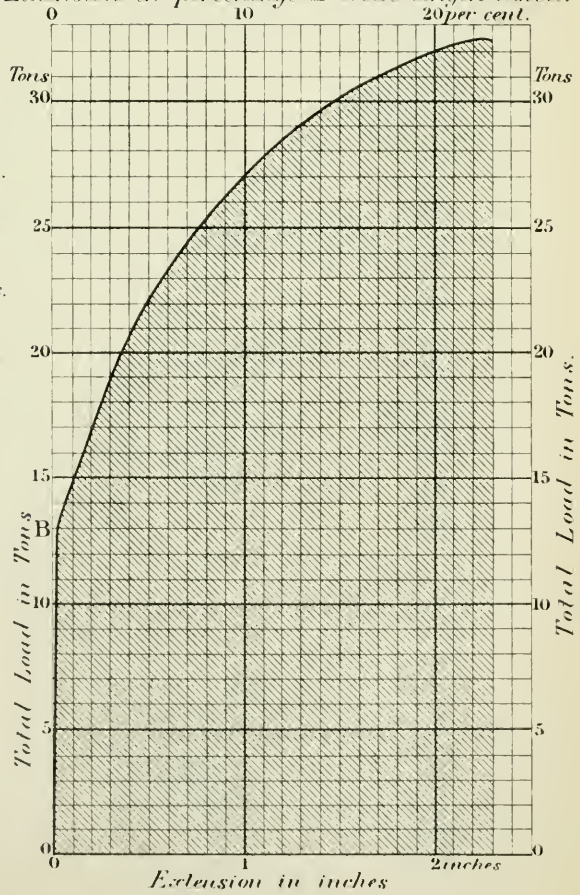
Fig 12.

Delta Metal Bar turned to 1 sq. inch.

Maximum Load 32·41 *Tons.*

Elongation 2·30 *ins. in* 10 *ins.*

Mechanical Work of rupture 61 *inch-tons.*



(Proceedings last M. E. 1886.)

AUTOGRAPHIC TEST-RECORDER.

Autographic Apparatus used by Professor Kennedy.

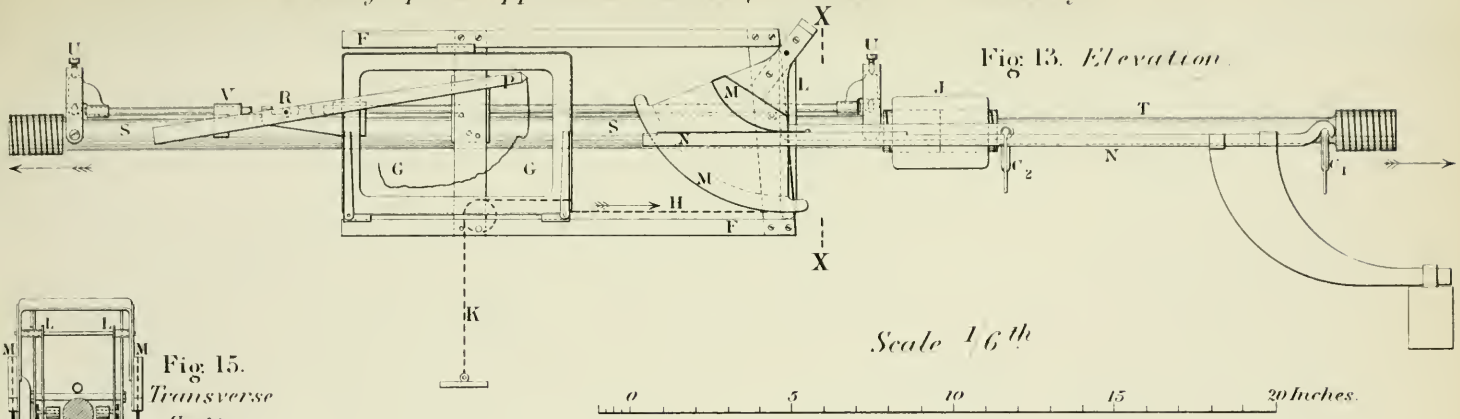


Fig. 13. *Elevation.*

Scale 1/6th

0 5 10 15 20 Inches.

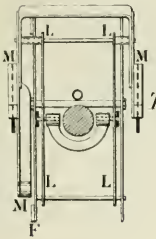
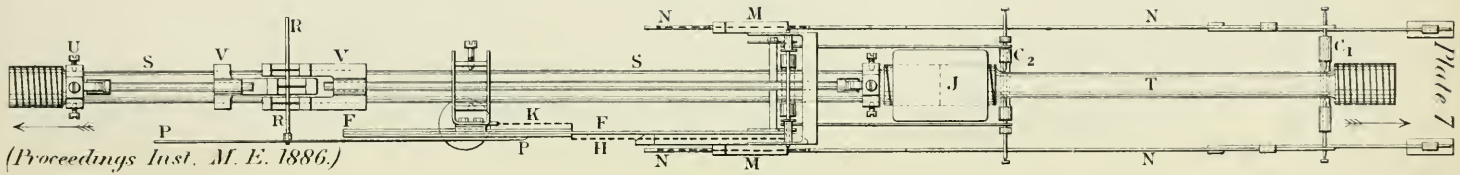


Fig. 15. *Transverse Section at* **XX**.

Fig. 14. *Plan.*

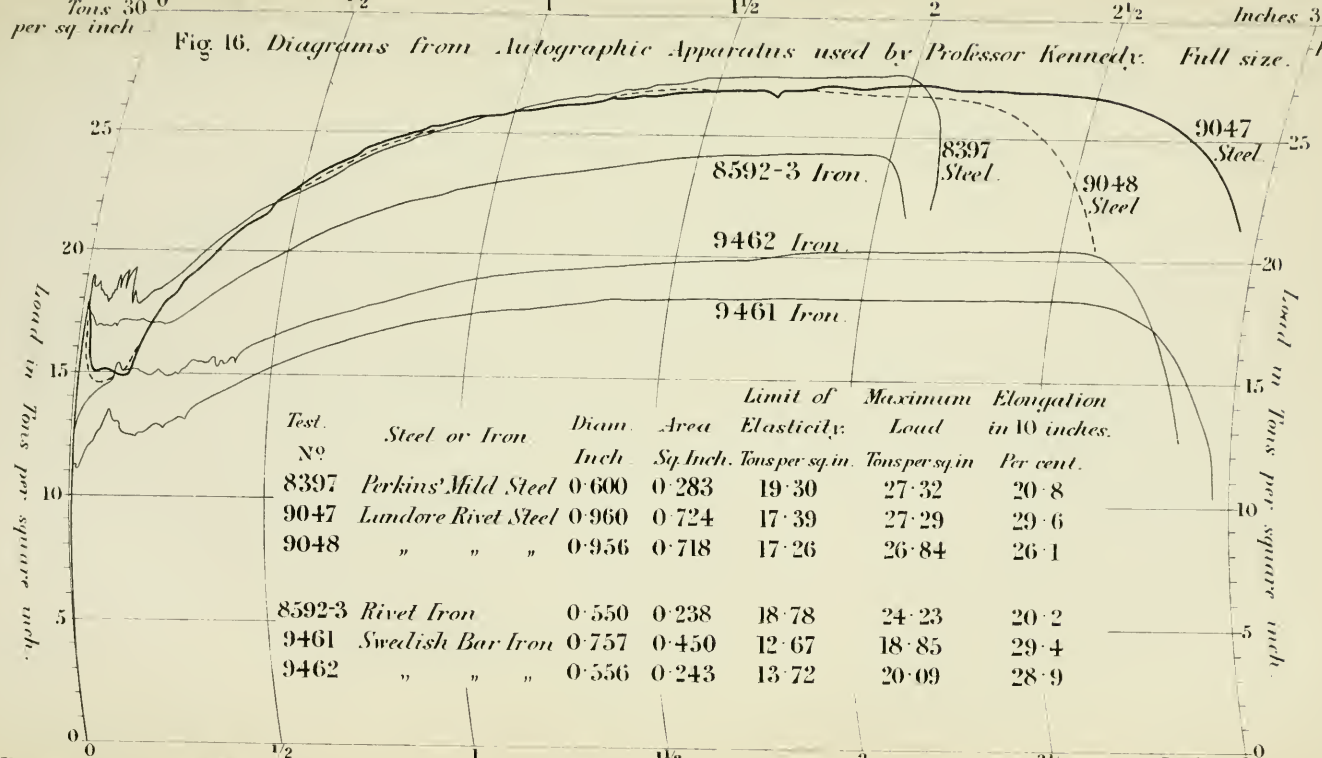


(Proceedings Inst. M. E. 1886.)

Plate 7.

AUTOGRAPHIC TEST-RECORDER.

Fig. 16. *Diagrams from Autographic Apparatus used by Professor Kennedy. Full size.*



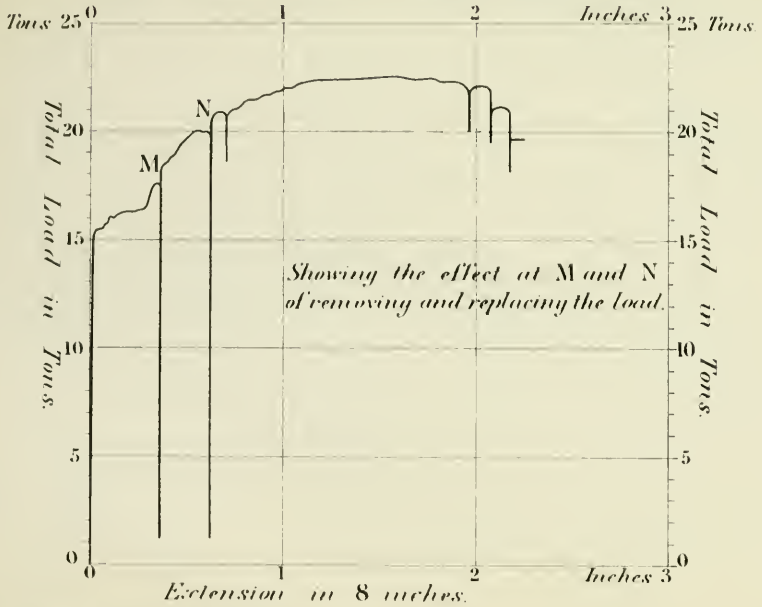
Test. Nº	Steel or Iron	Diam. Inch	Area Sq. Inch.	Limit of Elasticity. Tons per sq. in.	Maximum Load Tons per sq in	Elongation in 10 inches. Per cent.
8397	*Perkins' Mild Steel*	0·600	0·283	19·30	27·32	20·8
9047	*Lundore Rivet Steel*	0·960	0·724	17·39	27·29	29·6
9048	„ „ „	0·956	0·718	17·26	26·84	26·1
8592-3	*Rivet Iron*	0·550	0·238	18·78	24·23	20·2
9461	*Swedish Bar Iron*	0·757	0·450	12·67	18·85	29·4
9462	„ „ „	0·556	0·243	13·72	20·09	28·9

(Proceedings Inst. M.E. 1886.)

Plate 8.

Diagrams from Autographic Apparatus used by Professor Unwin. Half full size.

Fig. 17. *Steel Plate.* *Area 0·854 sq. inch.*



(Proceedings Inst M E. 1886.)

Fig. 18. *Lowmoor Iron Plates.*

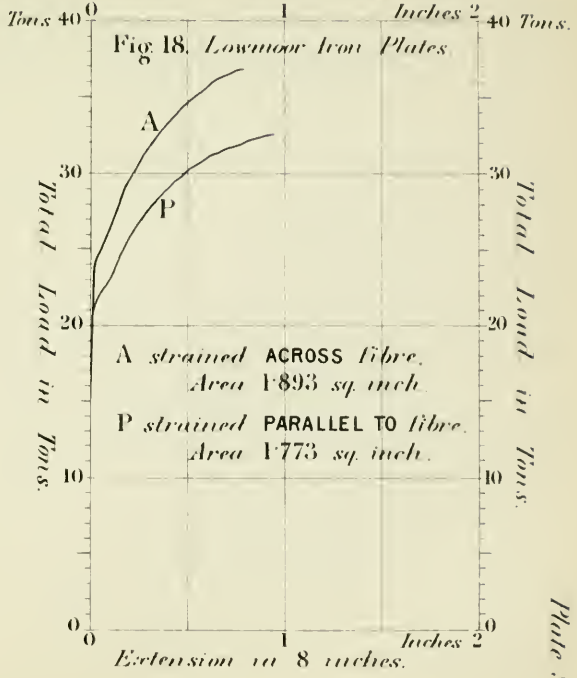
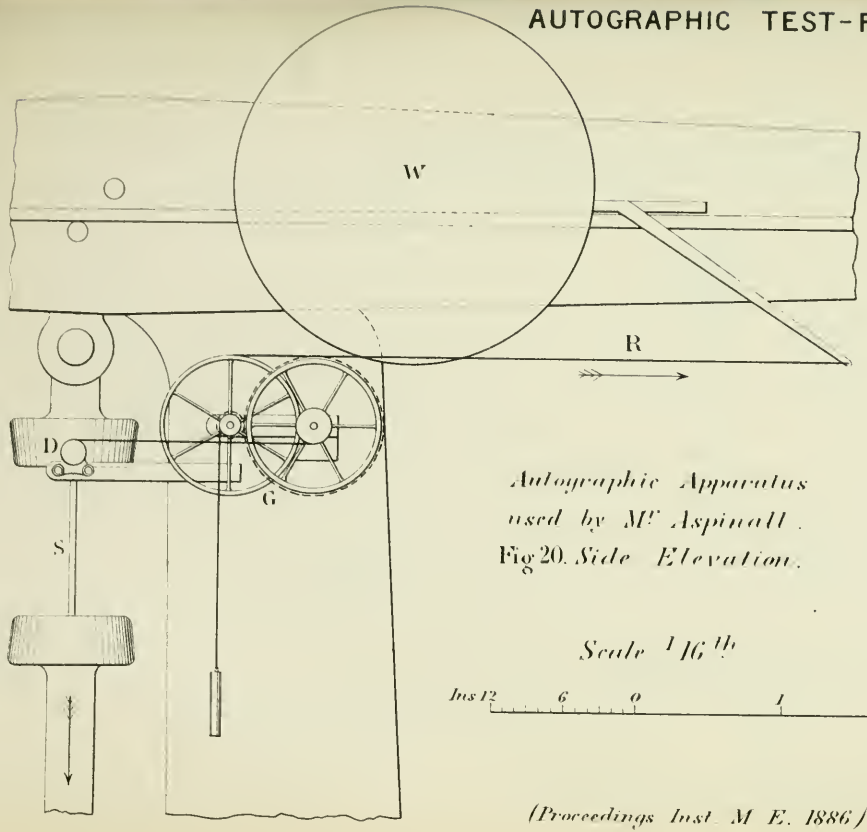


Plate 9.

AUTOGRAPHIC TEST-RECORDER.



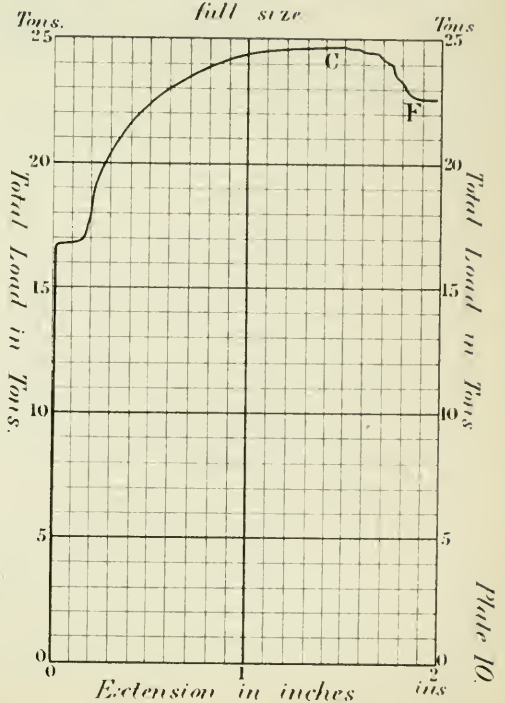
Autographic Apparatus used by Mr Aspinall.

Fig 20. *Side Elevation.*

Scale 1/6 th

Ins 12 6 0 1 2 Feet

Fig 19. *Diagram from Bolton Steel Boiler-Plate Specimen 1·8 inch × 0·493 inch, full size*



(Proceedings Inst M E. 1886)

AUTOGRAPHIC TEST-RECORDER.

Autographic Apparatus used by Mr Aspinall.

Scale 1/4 th

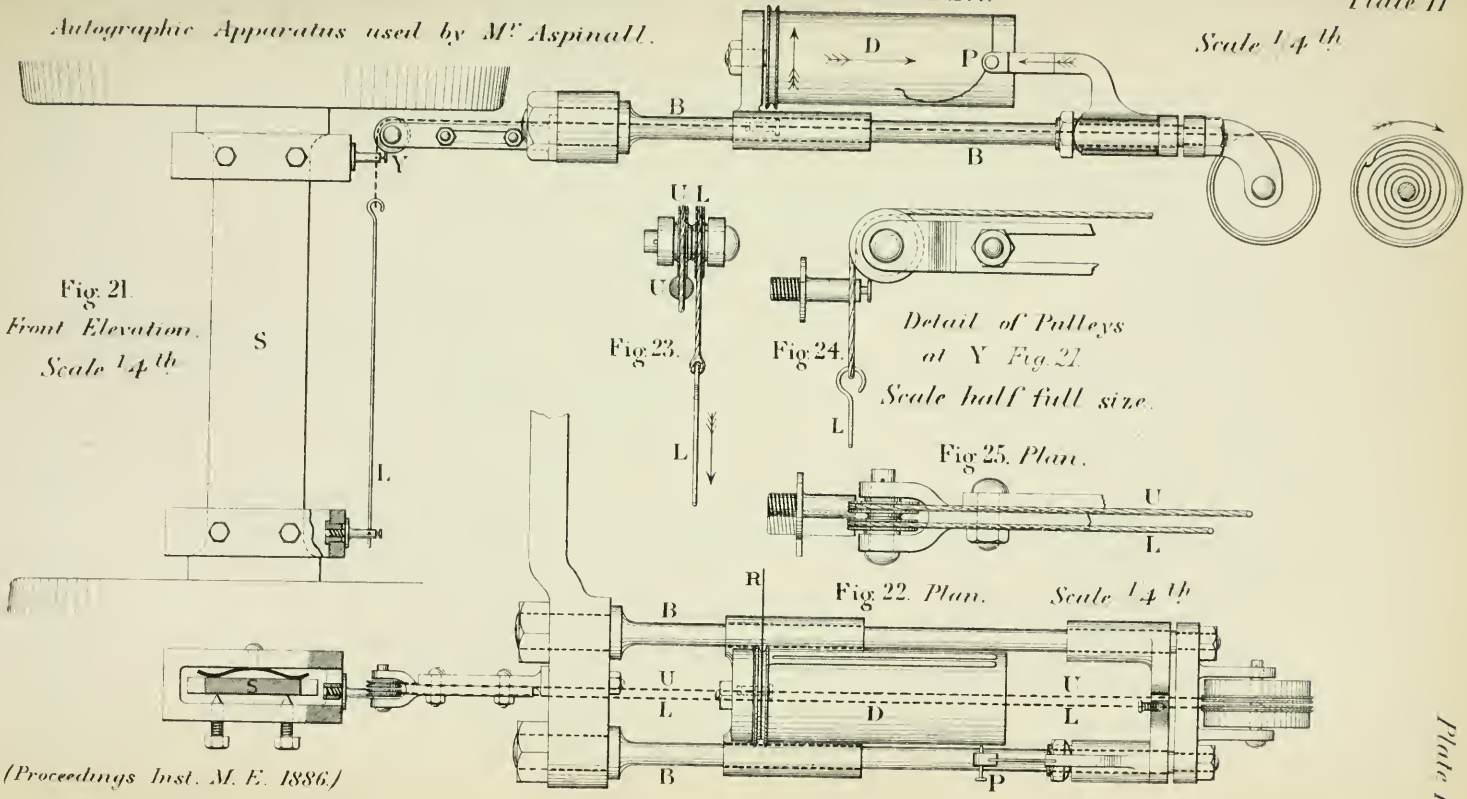


Fig. 21.
Front Elevation.
Scale 1/4 th

Fig. 23.

Fig. 24.

Detail of Pulleys at Y Fig 21.
Scale half full size.

Fig 25. *Plan.*

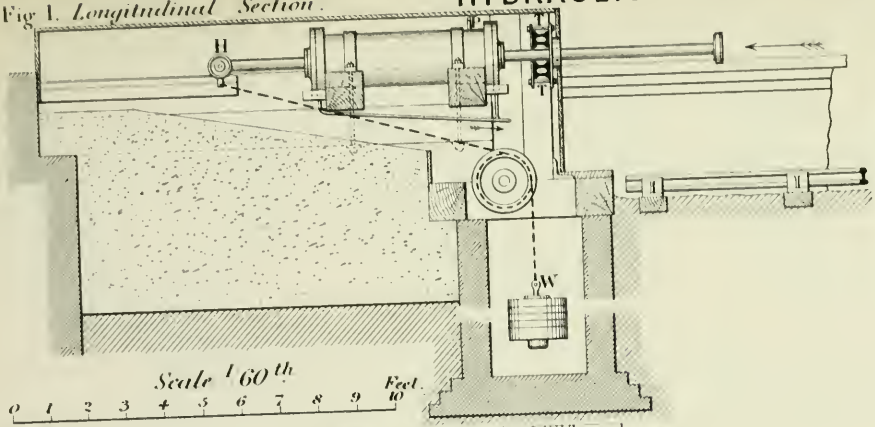
Fig 22. *Plan.* *Scale 1/4 th*

(Proceedings Inst. M. E. 1886.)

Plate II

HYDRAULIC BUFFER-STOP.

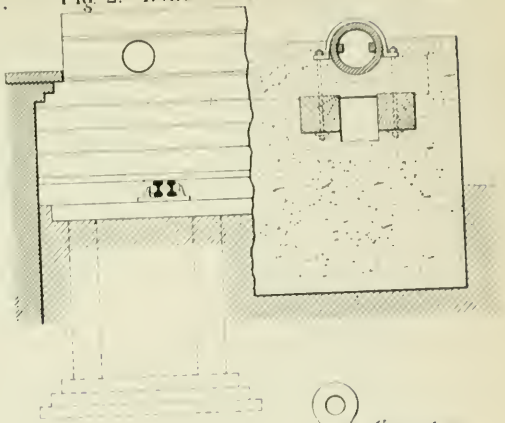
Fig 1. *Longitudinal Section.*



Scale 1/60th

0 1 2 3 4 5 6 7 8 9 Feet 10

Fig 2. *Transverse Section.* *Plate 12.*



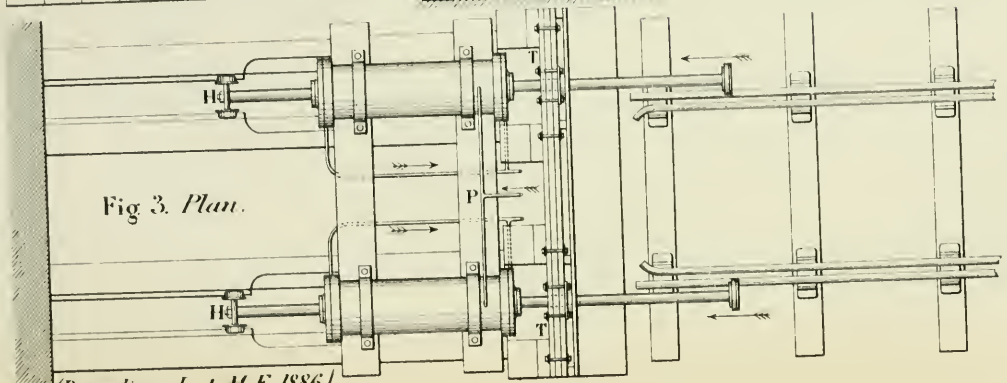
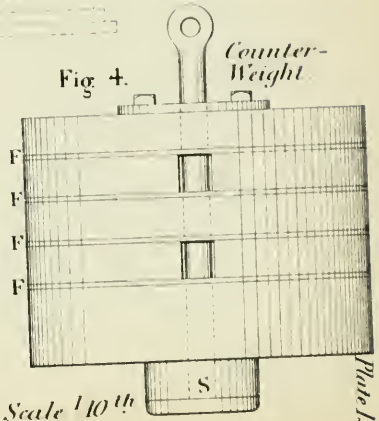


Fig 3. *Plan.*

Fig 4. *Counter-Weight*



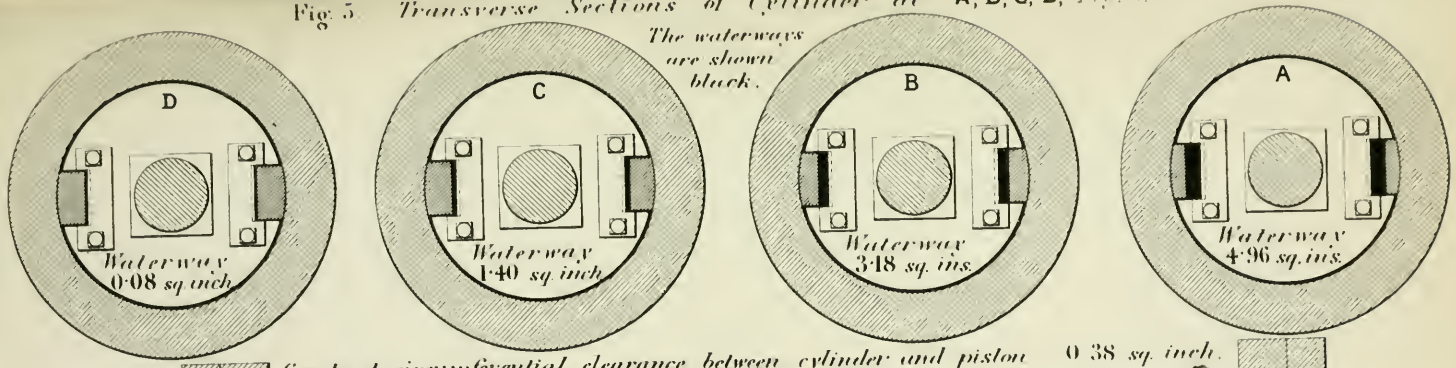
Scale 1/10th

Plate 12.

(Proceedings Inst. M. E. 1886.)

HYDRAULIC BUFFER-STOP.

Fig. 5. *Transverse Sections of Cylinder at* A, B, C, D, *Fig. 6.*



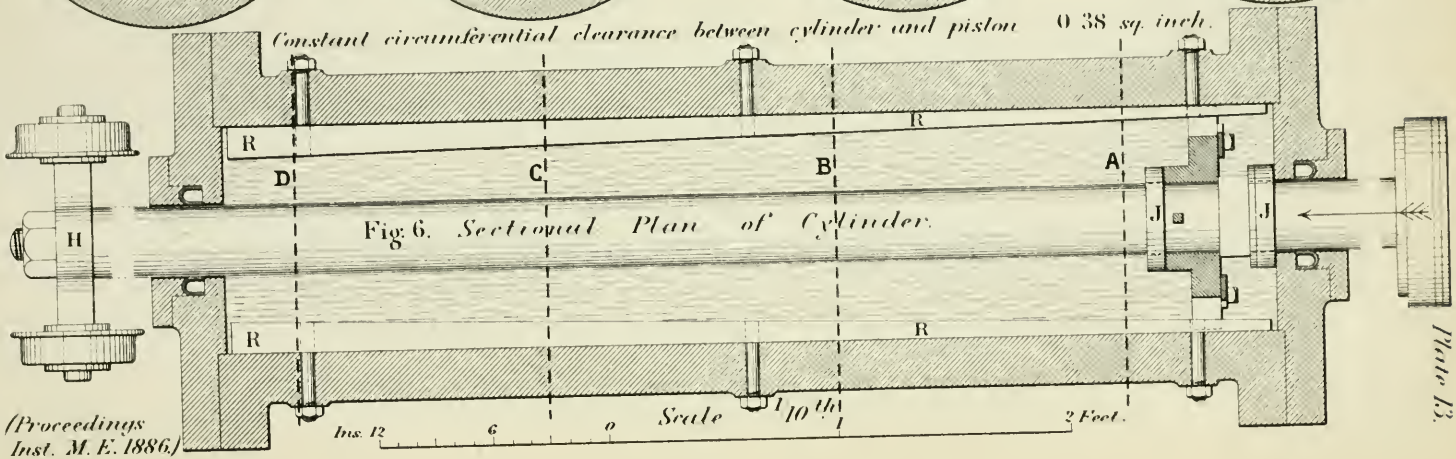


Fig. 6. *Sectional Plan of Cylinder.*

(*Proceedings Inst. M. E. 1886.*)

Institution of Mechanical Engineers.

PROCEEDINGS.

May 1886.

The Spring Meeting of the Institution was held in the rooms of the Institution of Civil Engineers, London, on Thursday, the 6th of May 1886, at Half-past Seven o'clock p.m.; Jeremiah Head, Esq., President, in the chair.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and that the following twenty-five candidates were found to be duly elected:—

MEMBERS.

John Francis Albright,	London.
Thomas Blandford,	Corbridge.
Henry Cambridge,	Cardiff.
Thomas Dale,	Kirkcaldy.
William Ogden Dayson,	Ebbw Vale.
David Grove,	Berlin.
John Boyd Harvey,	Iquique.
Charles William Hollis,	Nottingham.
Robert Matthews,	Manchester.
Thomas Midelton,	Sydney.
William Charles Mountain,	London.
Alfred Parry,	Calcutta.
James Edward Ransome,	Ipswich.
John Robinson,	Cardiff.

HORATIO SANDFORD,	Gravesend.
WILLIAM HENRY SCHOLES,	Buenos Aires.
JAMES SCOTT,	Consett.
JAMES MILN SMALL,	London.
CHARLES CAMPBELL WORTHINGTON,	New York.
JAMES WYLIE,	Trinidad.

GRADUATES.

JOHN BROUNLIE,	London.
WILLIAM STIRLING HALSEY,	Amritsar.
JOHN HOWELL HOSGOOD,	Cardiff.
CHARLES WHITBREAD SILCOCK,	Stony Stratford.
ROBERT JOHN WALKER,	Dalbeattie.

The following Paper was then read and discussed:—

On the Distribution of the Wheel Load in Cycles; by Mr. J. ALFRED GRIFFITHS, of Coventry.

Shortly after Ten o'clock the Meeting was adjourned till the following afternoon. The attendance was 62 Members and 60 Visitors.

The ADJOURNED MEETING of the Institution was held at the Institution of Civil Engineers, London, on Friday, the 7th of May 1886, at Three o'clock p.m.; JEREMIAH HEAD, Esq., President, in the chair.

The following Papers were read and discussed:—

On the Raising of the Wrecked Steamship "Peer of the Realm;" by Mr. THOMAS W. WAILES, of Cardiff.

On Refrigerating and Ice-making Machinery and Appliances; by Mr. T. B. LIGHTFOOT, of London.

On the motion of the President a vote of thanks was unanimously passed to the Institution of Civil Engineers for their kindness in granting the use of their rooms.

The Meeting then terminated. The attendance was 53 Members and 31 Visitors.

In the evening the Annual Dinner of the Institution was held at the Criterion, Piccadilly, the President occupying the chair, and was largely attended by the Members and their friends.

ON THE DISTRIBUTION OF THE WHEEL LOAD IN CYCLES.

BY MR. J. ALFRED GRIFFITHS, OF COVENTRY.

In the absence of definite experiments on the running resistance of Cycle Wheels under the multitudinous variations in speed, in road-surface, in softness and diameter of rubber tyres, and in lubrication of axles, it is a difficult matter to separate the influence which the Distribution of the Wheel Load exerts upon the efficiency, from the variations, often much greater, which are due to these other causes. It may be well at the outset to state that the manner in which the size of wheel affects resistances depends very largely on the character of the road surface. Thus on any level and smooth pavement the rolling resistance of small wheels is not very much greater than that of large ones; but on a macadamised road in ordinary condition the difference of the resistance is very material; and if the road surface be rough and lumpy, loose and soft, or muddy and sticky, the resistance of small wheels is considerably greater than of large ones. Inasmuch as the majority of roads have not a smooth surface, but are full of irregularities—either of the nature of isolated lumps, as in rain-washed and worn macadam and in rough sett-pavements, or of the nature of short undulations in a surface otherwise tolerably smooth—it is necessary practically to consider the best kind and arrangement of wheels for imperfect or ordinary roads. On the smooth floor of a show-room it is difficult to detect much variation of resistance in well-constructed cycles; and it is only when they are tried at a fair velocity on an ordinary road with varying gradient and surface that the real importance is appreciated of a proper distribution of the wheel load on the various sized wheels.

For the greater resistance of small wheels two reasons may be assigned:—firstly, that a small wheel has a shorter length of rubber tyre in contact with the ground, and consequently the power lost in grinding the rubber internally is greater than with a large wheel, although this difference may be partially or completely neutralised by giving the smaller wheel a broader elastic tyre; and secondly, in passing over small stones or lumps the smaller wheel has a more sudden lift, causing less steady driving and greater friction on the bearings. On the other hand small wheels have advantages over large wheels in the saving of dead weight and in the reduction of air resistance. Although cycle wheels with wire spokes offer little resistance to the passage of air laterally, yet when revolving at high velocity they carry with them a vortex of air, probably larger than the wheel, which offers practically as much resistance to progression as a solid body of the same dimensions as the space enclosed by the spokes.

Cycles for a Single Rider.

Classification of Cycles.—In considering generally how the wheels of cycles may be arranged, those may be termed small which are under 2 feet diameter, medium wheels would be from 2 to $3\frac{1}{2}$ feet diameter, and wheels above $3\frac{1}{2}$ feet diameter may be termed large. When there are several wheels, their functions may be different; though all must be utilised as carriers to a greater or less extent, the function of driving or of steering may be confined to one or more. For the present purpose the convenient classification of cycles is primarily according to the number of wheels employed, namely:—

One wheel . .	Unicycles or Monocycles.
Two wheels . .	Bicycles and Dicycles.
Three wheels . .	Tricycles, represented by four classes, A, B, C, D—
	A—Meteor and Humber Tricycles.
	B—Salvo and Premier Tricycles.
	C—Two-Track Tricycles.
	D—Rudge Tricycle.
Four wheels or more .	Quadricycles or Tetracycles, Pentacycles, &c.

A secondary classification might be based on the relative positions and sizes of the driving, steering, and idle wheels; and the most important subdivision depends on the position of the driving wheels, whether behind or in front of the rider and machine generally. Frequently they are spoken of as front-steerers and rear-steerers; but it is really the position of the driving wheels that affects the character of the machine, because in every cycle all the wheels participate in the duty of causing it to move in a curve, on account of the axles being turned at an inclination to each other in plan. The designation front-steering or rear-steering simply implies that the front or the rear wheel can be swivelled with respect to the frame of the machine.

The wheels, where there are more than one, must be connected by some sort of frame; and as a rigid body with more than three points of support cannot have all in continuous contact with an irregular surface whilst moving over it, the frame of any cycle with more than three wheels must have a joint or flexible part for allowing the wheels to follow the ground and take a continuous bearing. There are many four-wheeled cycles with rigid frames, in which one wheel is not intended to bear continuously on the ground, but only does so in emergencies. These will therefore be treated as tricycles, the three wheels continuously in contact with the ground being alone regarded. In this respect popular terminology is rather loose, the Rudge Sociable, Fig. 42, Plate 32, and the Carver Tandem, Fig. 46, Plate 34, being often called tricycles, though having four carrying wheels; whilst the Otto dicycle, Fig. 13, Plate 20, is sometimes called a "tricycle with only two wheels."

Efficiency of Cycles.—The efficiency of cycles cannot be judged regardless of the purpose for which they are intended. They may therefore be roughly classed according as they are intended for racing, for general road riding or touring, or for carrying passengers or goods. It is sometimes asserted that the fastest cycle on the racing path must be the one most easily propelled on the road, and therefore be the best for touring. But a truer way of stating the case is the converse, namely that "the best roadster makes the best

racer:" that is to say, the cycle which has the most economical application of driving power, and the best distribution of wheel load for general use on ordinary roads of varying surface and gradient, will be the best for racing, when divested of adjuncts not needed on the racing path—such as brakes, seat springs, foot rests, baggage holders, and appliances for hill climbing or for varying the driving power—as well as when its dead weight is also reduced to a minimum which would give insufficient strength to stand the jolting on ordinary roads. A racer must be adjusted permanently as though the road were not level but were continuously up hill, so that the rider's entire energy shall be converted into velocity. The same principles which apply to roadsters will apply also to carriers.

Hence the following five points of efficiency may be taken to apply to cycles generally:—

1. *Reduction of dead weight* by the avoidance of very large wheels and of heavy or purely ornamental or unnecessary framing.

2. *Reduction of resistance* by avoidance of very small wheels, and by employment of the best designs in bearings and in driving mechanism for the diminution of internal friction.

3. *Perfection of load distribution* by entire avoidance of wheels that neither transmit motive power nor assist the steering, and by concentration of the load on the driving wheels and reduction of that on the steering wheels.

4. *Stability* when in motion both on the straight and round curves; when on a smooth surface, and also on a rough and lumpy road; and when the brake is applied either suddenly or gradually.

5. *Arrangement* of load and driving mechanism, so that the distribution of the wheel load shall be as good on rising or falling gradients as on a level.

How these five points of efficiency are exemplified in different cycles will now be considered more in detail: firstly, with regard to a very few of the standard cycles for single riders; and secondly, with regard to special cycles, which for various objects deviate from those standards.

ONE-WHEELED CYCLES.—UNICYCLES OR MONOCYCLES.

Very much ingenuity has been expended in devising velocipedes with only one wheel; and although they have obviously the advantage of a perfect distribution of wheel load, yet their want of stability in all directions renders the balancing and riding of them very difficult, and almost confines their use to acrobatic performances on level ground. It may be noticed however that the simplest of all the monocycles, which indeed scarcely rises to the dignity of a mechanical combination—namely the sphere or globe driven by an acrobat standing and balancing himself upon the top—can be propelled with safety up and down inclines and spiral paths so steep that few riders on more elaborate cycles would venture upon them.

TWO-WHEELED CYCLES.—BICYCLES AND DICYCLES.

The two wheels may be arranged either to run both on the same track, as in ordinary bicycles; or to run in two tracks side by side, as in the Otto and similar cycles, for which the name dicycle has been proposed.

In the ancient "hobby horse," shown in Fig. 1, Plate 14, and in the diagram, Fig. 61, Plate 42, which was propelled by the feet touching the ground, the weight is equally distributed between the two equal or nearly equal wheels, both of which are carriers and neither a driver; and so far the distribution of load is good. But when driving mechanism was added, either the front or the rear wheel might be propelled: so that there are two classes of bicycles to be considered, namely front-drivers and rear-drivers.

Front-Driving Bicycles.—When cranks were added to the front wheel of the "bone-shaker," Fig. 2, Plate 14, and Fig. 62, Plate 42, it was found necessary to increase the load on the leading or driving wheel, in order to get sufficient adhesion to prevent slipping; and the rider's weight being thus placed mainly on the front wheel, it was found possible to reduce the size of the hind wheel on account of its reduced load.

In the bicycles of the present day, Fig. 3, Plate 15, and Fig. 63, Plate 42,—and particularly in those for racing purposes,—this principle is probably carried very nearly to its possible limit. The rider is seated only just so much behind the centre of the front wheel as is necessary for stability; and there is the utmost possible difference between the sizes of the two wheels, the driver being the largest that the rider can reach, and the trailing wheel the smallest that will carry enough rubber-tyre to stand the increased wear due to its shorter circumference. In the average bicycle of about 40 lbs. dead weight, the position of the saddle may practically be so adjusted that only about 10 per cent. of the rider's weight is left on the small rear wheel, and the remaining 90 per cent. comes on the large driving wheel. With an average rider of say 12 stones = 168 lbs. weight, the total load on the ground would accordingly be about 183 lbs. at the front wheel, and about 25 lbs. at the hind wheel. The rider however, by inclining his body forwards or backwards, and by altering the pressure of his feet on the pedals, has the power of varying this distribution very considerably; and on this variation depends the possibility of riding down steep hills. With 10 per cent. of the rider's weight on the back wheel of a 50-inch bicycle, his centre of gravity will be at a height of about 60 inches from the ground, and its distance behind the centre of the driving wheel will be only one-tenth of the wheel base of about 30 inches, that is it will be about 3 inches, giving an angle from the vertical of 3 in 60, or 1 in 20. Hence in going down an incline steeper than this moderate gradient the rider would fall forwards unless he saved himself by leaning backwards. Again when travelling at considerable speed, if the large wheel is checked by a comparatively small stone or rut, it is obvious that the machine acts as a fine wedge with a lift of 1 in 20, driven by the rider's whole momentum, to lift him over the front-wheel base. This action must be met by careful riding; but when it occurs unexpectedly a fall frequently results. A point may here be noticed, which is of greater importance in certain other cycles, but also affects this question. If in an ordinary bicycle the driving-wheel be fastened to the ground with its cranks horizontal, then a rider, without actually moving his

body or legs, can, by transferring the pressure of his feet from the forward to the backward pedal, greatly reduce the weight on the hind wheel; or *vice versâ*, by throwing the pressure on the forward pedal, the weight on the hind wheel is increased. The effect on the hind wheel is really produced by the rider's reacting push or pull upon the steering handle-bar or upon the seat. In geared bicycles this action is more important, as the driving cranks are attached to the main frame and re-act directly upon it. When a bicycle is being propelled at high velocity, the pressure on the pedals approximates in amount and direction to that which would occur under the latter of the two conditions above mentioned in connection with the driving-wheel fastened to the ground; so that the muscular action in riding forwards slightly increases the stability of the machine. The amount of weight thus transferred depends more on the rider's muscular power than on his weight; but it is found by experiment that a rider of moderate strength can easily increase the total load at the back wheel from 20 lbs. up to 40 lbs.

In the early bicycles the brake was applied to the back wheel; but it is readily seen why this was unsatisfactory. With the light load on the back wheel, the brake easily locked or skidded it, greatly to the detriment of the rubber tyre; and the total retarding force, being but a small fraction of the load, was of very little use down even moderate inclines. But what little retarding power was afforded by the rear brake was at any rate so applied as not to diminish the stability of the machine. On the contrary the brakes now fitted to bicycles are invariably put on the front wheel; and although in that position they do not spoil the tyres, yet their application requires great caution; otherwise the spoon on touching the wheel will inevitably pull the rider over in front. To obviate this danger, numerous so-called safety bicycles have of late been introduced, in which the rider's weight is placed more to the rear, and special mechanism is used for bringing the driving pedals more nearly vertically under the saddle. The result of course is primarily to increase the resistance, by the friction of the additional mechanism and by the increased load on the smaller wheel. But in practice it has been found that the increased stability obtained, and the improved

mechanism, enable the rider to perform more work and to realise some remarkable results in speed and distance. Amongst the safety bicycles in which this distribution of wheel load is thoroughly carried out may be mentioned the 'Xtraordinary, Fig. 4, Plate 15, and Fig. 64, Plate 42; the Facile, Fig. 5, Plate 16, and Fig. 65, Plate 43; the Challenge, Fig. 6, Plate 16, and Fig. 66, Plate 43; and other similar machines, in most of which the increased load on the hind wheel is met by an increase in diameter of from 50 to 70 per cent. In all of these there is greater facility and safety in the application of the brake, as the line from the rider's centre of gravity down to the front-wheel base is so very much less steep than in the ordinary bicycle. Hence the brake may be put "hard on" suddenly, without the same disastrous results.

In other safety bicycles, like the Kangaroo, Fig. 7, Plate 17, and Fig. 67, Plate 43, and its imitators, the load is not carried so far back; and the stability is so far sacrificed that in the opinion of many riders these cycles are no more worthy of the name "safety" than is the ordinary bicycle. But in justice to manufacturers it must be mentioned that any rider wishing a real safety bicycle can generally get his wheel load suitably adjusted for securing that object. Yet it is possible to overdo the backward position, as in an experimental bicycle which came under the author's notice, where the peculiar construction rendered the driving leverage very great, and it was found that 50 per cent. of the load was insufficient to prevent slipping of the driving wheel, with consequent defect both of action and of steering in a machine which otherwise had many excellent points.

Rear-Driving Bicycles.—In this class the stability of their prototype, the hobby horse, is retained, the rider being placed approximately midway between the wheels.

The American Star bicycle, Fig. 9, Plate 18, is largely used in the United States, and resembles an ordinary bicycle reversed end for end, with the small wheel in front; but the large driving wheel is here fixed in the frame, while the small pilot wheel swivels for adjusting the steering. The saddle is so nearly balanced over the driving wheel

that the rider can easily lift the pilot wheel off the ground whilst riding, and even use it as a bat or racket for ball games.

In this country nearly all the rear-drivers are made with a medium-sized wheel geared up; the earlier patterns are the Birmingham Small Arms, Fig. 8, Plate 17, the Pioneer, and the Humber, Fig. 10, Plate 18, and Fig. 68, Plate 43. In all of these the front wheel is the smaller, and carries more than one-third of the total load, which is a much larger proportion than is borne by the hind wheel of an ordinary bicycle. The stability under the brake when applied to the hind wheel is perfect; for however much the brake may check that wheel, the front wheel offers a fulcrum whereby the rider is prevented from falling forwards. At the same time a new element of resistance is introduced by placing the smaller wheel in front, in which position it is much more liable to dig into loose or soft ground than when it is in the rear. Moreover the jolt of a leading wheel over a stone gives a greater jar to the frame and to the rider seated nearly midway than the same jolt of a trailing wheel; whence it would be preferable that the leading wheel should be the larger of the two. In these front-steering bicycles, as much as in those with the smaller wheel behind, the rider's muscular effort varies the distribution of the load when working; the act of driving, although it cannot actually lift the front wheel from the ground, yet reduces somewhat the load upon it, and to the same extent counteracts on soft ground the digging action due to the position of the leading wheel. In the Rover, Fig. 11, Plate 19, and Fig. 69, Plate 43, the same front-steering arrangement is used, but the leading wheel is of medium size and actually larger than the rear driving wheel. Although this larger front wheel requires a heavier frame, it is found, as might be expected, that the whole machine has a reduced resistance and is an excellent roadster, whilst the extra gyroscopic stability of the larger front wheel greatly improves the steering. Many bicycles are now being made on this plan with equal or nearly equal medium-sized wheels; and they have the very great advantage of reduced vibration, compared with cycles in which part of the load is carried on a small wheel rigidly attached to the frame that carries the rider's seat.

In the Kaiser safety bicycle, Fig. 12, Plate 19, designed by the author, the load is carried nearly midway between two equal medium-sized wheels, as in the hobby horse or the Rover; and in addition the rider's seat is disconnected from the main frame by being placed on the top of a pillar, which is hinged at its lower end as closely as possible to the treadle or crank axle, so that the swinging of the seat pillar will cause as little variation as possible in the distance from the seat to the cranks. Thus the horizontal component of the motion of the seat, due to the rise and fall of the wheels in passing over lumps in the roads, is eliminated by the hinge joint; and the vertical component can be neutralised by a seat spring of long range, such as the double-action cradle-spring. For assisting the rider to balance himself on the top of the pillar, the seat is pulled forwards by a strong spiral spring connecting it with the steering head. Thus the rider is balanced between the forward pull of the spring, and the horizontal component of his own weight on the top of the pillar raking backwards. The maintenance of this position, which at first sight might appear to be one of unstable equilibrium, is found in practice not to require the slightest effort on the part of the rider, who in travelling over very rough pavement is almost unconscious of seat vibration. A further advantage of the swinging seat-pillar will be dealt with later on.

The relative stability of the various kinds of bicycles may also be compared by noting the position of the path of motion of the pedals, as shown by the thick dotted line in Figs. 62 to 69, Plates 42 and 43, with respect to the shaded triangle enclosed by the lines drawn from the saddle down to the ends of the wheel-base. Thus in Figs. 62 and 63 the pedal path is entirely outside this triangle of stability; in Figs. 64, 66, and 67, it lies partially inside; whilst in Figs. 65, 68, and 69, it is entirely within the triangle, so that no modification of the pedal pressures can reduce the hind-wheel load below zero.

For speed in road travelling the dwarf bicycles have excelled the ordinary. In a ride on 27th September 1884 with the Kangaroo bicycle, Fig. 7, Plate 17, the first three riders accomplished 100 miles respectively in 7·18, 7·78, and 7·99 hours; whilst on 26th

September 1885 with the Rover bicycle, Fig. 11, Plate 19, the times were 7·09, 7·28, and 7·49 hours. The road surface and weather in the first ride were both favourable, whilst on the latter occasion the road surface was in many places in bad order. The winning bicycles were in both rides ridden by the same gentleman, showing that the high results obtained are to be ascribed quite as much to the excellent training and condition of the riders as to the inherent merits of the machines. In a still more recent competition on 20th October 1885 over level roads carefully selected and in favourable weather, still better results were obtained with the Kangaroo bicycle, the first three riders performing the distance of 100 miles in 6·65, 6·87, and 7·22 hours.

Dicycles.—The Otto, Fig. 13, Plate 20, and all dicycles—in which the two wheels run in two tracks, side by side—differ from other cycles in the total absence of small wheels carrying even a small fraction of the load, and in the perfect lateral stability caused by the widening of the wheel base. Their advantages over the bicycle are:—firstly, the perfection of the wheel-load distribution, as the entire load is divided equally between two equal large wheels, each of which is generally both a driver and a steerer; secondly, the very much lower position of the centre of gravity; and thirdly, the great reduction in vibration at the seat, particularly in the horizontal component. Their disadvantages are that they are more bulky, and the rider has not such a good view of the country when touring; and they are also subject in rather a higher degree than bicycles to absence of forward stability when the brakes are applied. But an important improvement in the propelling mechanism, consequent on this absence of forward stability, will be considered later on.

In the original Otto machine there is the great defect that when running on curves one wheel only can drive, and the other must either be allowed to run idle as a carrier, or on a downhill curve must be retarded by the brake. This disadvantage is remedied in the Kingston dicycle shown by Mr. C. Kingston Welch at the Inventions Exhibition last year, and also in the new central-geared Otto dicycle; but a positive gearing is yet wanted which shall drive

both wheels of a dicycle at any determinate and variable differential speed, and which shall be as simple and reliable as the Fowler balance gear applied to traction engines and tricycles.

Three-Wheeled Cycles.—Tricycles.

The next step at increased stability—the introduction of a third wheel—leads to so many possible variations in the distribution of the load, on driving wheels, steering wheels, and idle or carrying wheels, that only a few leading types of tricycles can be noticed in detail. In Figs. 70 to 73, Plate 44, are represented in plan four classes, showing how the three points of support can be arranged with respect to the line of motion through the saddle; namely—

Class A, wheel triangle with base forwards		Plate 44, Fig. 70.
„ B, „ „ „	apex forwards	„ „ 71.
„ C, „ „ „	apex forwards laterally	„ „ 72.
„ D, „ „ „	base and apex at sides	„ „ 73.

and to one or other of these four classes the wheel-plan of any tricycle may be referred. The shaded triangle in each diagram is bounded by lines drawn through the points of support; and obviously the stability of a tricycle in any direction may be measured by the length of the line drawn from the centre of the saddle in that direction, other conditions being equal. Hence the greatest average stability in all directions is when the seat is exactly over the centre of the circle inscribed in this triangle. The position of the seat is practically confined to the centre line of motion, inasmuch as there would be no object in moving it to either side of this line.

Class A. *Wheel Triangle with Base forwards*, Fig. 70, Plate 44.—In the Front-drivers of this class two larger wheels of equal size are placed abreast, slightly in advance of the saddle, and one smaller wheel in the rear. In the Meteor, Fig. 14, Plate 20, and its followers, one only of the front wheels is a driver, and the other runs idly; the hind wheel is comparatively small, and steers by swivelling on a vertical axis through its own centre. In the Humber, Fig. 16,

Plate 21, and its followers, both of the front wheels are drivers, and the small steering wheel in the rear swivels round a vertical axis situated midway between the centres of the front wheels. The Rover tricycle, Fig. 15, Plate 20, is an intermediate machine, with Humber driving and Meteor steering.

The forward stability when running over small obstacles is here comparable with that of the bicycles of the type shown in Fig. 67, Plate 43, and there is the same liability to a spill forwards through careless riding. But as the tricycle is running on three tracks instead of only one, an obstacle on either of the lateral tracks causes a disturbance which is not balanced, and thereby tends to make the machine swerve from its straight course. When only one of the front wheels is a driver, another difficulty arises on any attempt being made to force the machine to a high speed, in consequence of the weight on the steering wheel being thereby so greatly reduced that the wheel slips sideways, and renders it almost impossible to keep a straight course. The defect is so great that the single-driving tricycles of this front-driving class have nearly ceased to be made, and are being replaced by modifications to be described later on.

Many tricycles, Figs. 18, 21, and 22, Plates 22 and 23, are also made with double clutch-driving gear. In either case the steering difficulty appertaining to single-driving tricycles of class A does not occur.

The double-drivers are very largely used. Although their forward stability is slight, it is still not less than that of a bicycle. An important point in the Humber, Fig. 16, Plate 21, and the Cruiser, Fig. 17, is that, as in going round a curve the seat swivels with the backbone, and the rider also touches the axle-frame with feet and hands, the load on the two front drivers then becomes divided unequally; the inner wheel, being brought nearer to the rider, has from 15 to 25 lbs. more load on it than the outer, which is removed further from him, thereby adding greatly to the stability when running slowly round corners, because the leverage is then greater from the rider's centre of gravity to the base of the outer wheel. This is strictly correct for low velocities only; at high speeds the centrifugal action in going round the curve will of course tend to

lift the inner wheel and thus to equalise the distribution, or even reverse the inequality if the turn be too sudden for the speed.

As in the case of bicycles, tricycles have been made with greater stability by carrying the seat back, with a proportionate increase in the load on the hind wheel and corresponding increased resistance of that small wheel. In the Quadrant No. 1 tricycle, when front-driving, Fig. 22, Plate 23, this result is largely neutralised by increasing the size of the hind wheel, and the seat is pretty nearly in the position of greatest stability. In the Monarch, Fig. 18, Plate 22, the seat is also well back, but more on account of the peculiar driving action; and only a small rear wheel is used. In the Excelsior, Fig. 19, Plate 22, in which only one of the two front wheels is a driver and the other runs idly, the latter is reduced to a size intermediate between the large driver and the small steerer; and is also sometimes placed a little in advance of the driver, making the wheel base a scalene triangle instead of the usual isoscele triangle, and thus getting a slightly increased leverage for preventing the brake-power from lifting the rear end of the machine.

In the Rear-driving tricycles of class A the defect of instability under sudden application of the brake is removed, generally by the brake being applied to the hind wheel, which here is of larger diameter and necessarily carries the greater part of the load; but even if the brake were applied to the front wheel, the main load is so far back that the machine would be stable.

One of the earliest rear-driving tricycles was the Challenge, Fig. 20, Plate 22, where the large rear-driver was driven by levers, and the rider sat in front of it, in a position but very little behind the front wheel-base. The somewhat cumbersome appearance of these machines, due to the necessarily large size of the hind wheel, has led to their disuse; and most of the recent rear-drivers of class A are made with a medium-sized driving wheel geared up to run faster than the pedal axle, so that its circumference travels as fast as that of the large wheel in the Challenge, without the necessity for very fast pedalling: thus securing many of the advantages which the dwarf bicycles have over those with large wheels. At the same time

the rider can be seated partially over the driving wheel, thereby increasing its adhesion and reducing the load on the pilot wheels.

The Gnat tricycle, Fig. 23, Plate 24, embodied all these points, and was very successful; but its manufacture unfortunately ceased through litigation.

In the Emperor, Fig. 24, Plate 24, the two front wheels and the hind driver are all of medium size. This tricycle bears exactly the same mechanical relation to the Rover bicycle that the Humber tricycle does to an ordinary bicycle; and differs from the Gnat chiefly in general proportions and in the mode of steering.

Class B. *Wheel Triangle with Apex forwards*, Fig. 71, Plate 44.—This is exactly like class A reversed end for end, the two large hind wheels being almost always both of them driving wheels, and the small steering wheel in the front. It is to this class of tricycle that balance-driving gear was first applied in 1877 by the late Mr. James Starley, who is said independently to have hit upon and adopted the well-known device,—consisting of a pair of bevil wheels facing each other and each gearing into an intermediate loose pinion,—which was used twenty years previously by Messrs. John Fowler and Co. for steam-traction tricycles of a heavier design than those now under consideration.

The seat is generally placed as far back as possible, so as to reduce the load on the steering wheel. Consequently the backward stability in this class is a minimum, and in the earlier tricycles a fourth or guard wheel was placed behind, and the machine was called the Salvo Quadricycle; but inasmuch as this fourth wheel came into use only during inexperienced or careless riding, the name quadricycle has been dropped, and the guard wheel has gradually been reduced to nothing more than a small metal disc or roller, generally screwed up fast on its pivot; and in the very latest machines there is only a tail support with a knob at its end. The Royal Salvo, Fig. 25, Plate 25, the Premier, and the Sparkbrook, Fig. 26, Plate 25, are standard tricycles of this class.

The most important point of advantage in tricycles of class B is their perfect stability under the action of the brake, because the front

steering wheel here supplies the fulcrum which is absent in the ordinary bicycle, as well as in tricycles of class A, where the effect of the brake was not so much to check the front wheels as to lift the hind wheel off the ground. Here on the contrary the application of the brake causes an increased load on the pilot wheel; and so far, by increasing the resistance, assists the check which is put on the drivers. The stability under the brake, and the consequent safety in going down hill, suggested the name Salvo given to the first tricycles of this make. In some tricycles the seat is brought so far forwards that the safety tail is dispensed with altogether; and notably in the Quadrant No. 8, when front-steering, Fig. 27, Plate 26, the consequent increase of load on the pilot wheel is met by a large increase in the wheel's diameter. In the Zephyr tricycle the front wheel is carried a foot farther forwards than in others, or even more; so that when the seat is brought forwards the consequent increase of load on the front wheel is proportionately less. Another style of tricycle recently becoming prominent on the racing path is the Cripper, Fig. 28, Plate 26, in which the seat is carried so far forwards that at first glance great resistance would be expected from the digging of the front wheel under its apparently heavy load; but the handles are so arranged as to supplement the lifting action already mentioned in connection with rear-driving dwarf bicycles, and when the tricycle is driven at the rider's best a considerable reduction of the front load takes place. Thus with the tricycle at rest the front load is about 20 lbs.; and if it be prevented from moving forwards whilst pressure is put on the forward pedal, the front load is reduced by about 10 lbs. No doubt when this tricycle is driven by a powerful rider against a maximum resistance, or at such a velocity that the resistance is equal to his strength, the reaction of the resistance has a similar effect to the holding of the machine whilst pressure is put on the forward pedal.

Class C. *Two-Track Tricycles*, Fig. 72, Plate 44.—If the pilot wheel in the preceding class B of tricycles is removed from the centre and fixed in line with one of the side wheels, the machine has then the obvious advantages of an open front and, for bad roads, of one

less track to be watched; but it presents also certain disadvantages. If the seat is kept fairly forward, as in the Royal Mail, Fig. 29, Plate 27, and the Empress, it is seen that the wheel base and stability to the left forwards as at L, Fig. 72, Plate 44, are very much less than at the same angle to the right forwards as at R through the apex of the triangle; and this inequality becomes more inconvenient on curves turning to the right. In the Spinaway tricycle designed by the author this defect is obviated, as will be described later on. In the Grosvenor tricycle, Fig. 30, Plate 27, the wheel on the same side as the pilot is not a driver, and is small in diameter; but the disadvantages of this arrangement are considered to be compensated by the system of compounding for two riders side by side. The Cunard two-track tricycle has similarly only one driver; but the idle wheel is not much reduced in size, and is on the opposite side to the pilot wheel.

Class D. *Rudge Tricycle*, Fig. 31, Plate 28, and Fig. 73, Plate 44. —This is essentially a single driver. The three wheels are arranged in two tracks, the large driving wheel being on the left hand and two small wheels on the right hand. Here it is obviously impossible to put more than half the load on the driver, whilst the two smaller wheels carry the remainder divided between them in the inverse proportion of their distances from the seat. But although only half the load can be put on the driver, this is yet a larger amount than in any of the three preceding classes A B C when only one wheel is used as driver. This tricycle shares the defect of all single-driving tricycles, that on a greasy road the load on the driving wheel is often not sufficient to prevent it from slipping. In the Rudge tricycle proper, both of the small side wheels are steering wheels; whilst some few tricycles have been built on this plan of wheel base with other schemes for steering that are less perfect. The main advantage of the Rudge tricycle is its great stability backwards as well as forwards, a property not possessed by either of the three preceding classes A B C; and its one defect, which restricts its comfortable use to fairly good roads and the racing path, is the large proportionate load on both of the small wheels (see Table II appended). At the same time this

very defect is itself attended with the important advantage that under no circumstances can the rider lift a wheel off the ground and so lose his steering power.

CYCLES FOR TWO RIDERS.—SOCIABLES AND TANDEMS.

These may be classified exactly as those for a single rider (page 129); and further as Sociables or Tandems, according as the two riders sit abreast or fore and aft. A sociable monocycle for two riders has been made by Mr. Pearce in 1881, Fig. 32, Plate 28, with a seat and driving gear mounted at each side of a single wheel. A tandem unicycle might be made on Mr. Otto's lines by mounting a seat fore and aft of a single wheel. But the riding of either would hardly be practicable, except as an acrobatic performance.

One-Track Tandems.—Mr. Rucker's tandem bicycle, Fig. 33, Plate 28, is practically two monocycles coupled together by a properly jointed backbone, so that the whole machine has very great stability fore and aft, with perfect distribution of wheel load, both wheels being equally drivers and steerers; and there are no small wheels to retard the joint propulsion. The only drawback, if it can be so called, is that a certain amount of concerted practice is necessary on the part of the riders to ensure steady steering and to secure proper balancing on curves.

The tandem safety or dwarf bicycle, Fig. 34, Plate 29, of the same maker has two wheels, medium and small, arranged as in Figs. 65 to 67, Plate 43. The two riders are both carried on the front or medium-sized wheel, and are nearly balanced, care being taken that the heavier rider occupies the back seat. Here the stability against forward falls cannot be greater than in the ordinary bicycle; and there would generally be a tendency to place less load on the hind or small wheel. This so far is good, and diminishes resistance, but at the cost of greater liability to a spill forwards.

The Shakespeare tandem bicycle and also Mr. Renouf's tandem are derived from the original hobby horse by placing a rider and driving gear to each wheel; and this mode of construction may be

so arranged that a lady can ride the front seat without requiring the divided skirt or other special costume.

Mr. Pausey's Pioneer one-track tandem tricycle has a medium-sized driving wheel with two seats and sets of driving gear, and two smaller wheels, namely a front or pilot wheel and a rear or trailing castor wheel. Its advantages are that it is convertible to single machines, and that both riders assist in steering.

Tandem and Sociable Dicycles.—Mr. Welch's tandem dicycle when perfected ought to be a very good machine, as the whole load is carried on two large wheels, between which two riders are balanced on a tandem frame. Both Mr. Otto and Mr. Welch could also build sociables on the plans of their single dicycles, which would have also the same advantages and defects as the machines for single riders.

Sociable and Tandem Tricycles.—Tricycles for two riders, Figs. 35 to 46, Plates 29 to 34, are built in so many varieties that only a few leading examples can be noticed. Either of the classes A and B, Figs. 70 and 71, Plate 44, may be widened to form a sociable, as shown by the dotted lines in Fig. 71: in which case it is essential that both of the large wheels should be drivers, and it is best that they should be driven in conjunction through balance gear, instead of being driven independently of each other.

Either class A or B may also be used for a tandem by mounting the two seats fore and aft. Up to the present time the class A, Fig. 70, Plate 44, has been the most popular for a tandem; but this construction, illustrated by the Humber tandem, Fig. 36, Plate 30, has all the same disadvantages or even dangers from small forward stability which have already been pointed out in the Rucker tandem dwarf bicycle. The objection is often met by providing a small wheel in front, which is generally some inches off the ground, but is supposed to prevent accident whenever the hind wheel is temporarily lifted by some obstacle or through oscillation in riding. The most noted of these tandem tricycles are the Humber, Fig. 36, Plate 30, and the Centaur rear-steerer. A much safer and more reliable tandem results from the conversion of class B, Fig. 71, Plate 44, as in the Centaur front-steerer, Fig. 35, Plate 29, and the Meteor tandem; and

to the same class must also be referred the Coventry Chair, Fig. 38, Plate 31, of Messrs. Starley and Sutton, and many carrier tricycles, such as the Despatch carrier, Fig. 39, Plate 31. With both A and B tandems, it is obviously possible to obtain very good distribution of load, balancing nearly the whole on the drivers, and leaving only so much on the small wheel as will ensure accurate steering.

The Rudge tricycle makes a very efficient tandem, Fig. 41, Plate 32, the only drawback being that it intensifies the already heavy load on the small wheels; and for this reason it is unsuitable for bad roads, as indeed is it also in its single form, although its compactness and convenience of stowage compensate for this drawback in districts where the roads are good.

Four-Wheeled Cycles.

Many cycles for two riders have been made with four wheels. As regards wheel-base they are all duplications of classes A B C D, Figs. 70 to 73, Plate 44; and almost without exception provision is made for removing one wheel and set of driving gear, so as to leave a single tricycle for one rider according to one or other of these four classes. In all of them also provision must be made in the framing of the extra wheel for flexibility in passing over uneven ground.

The oldest and most notable is the Coventry convertible sociable, Figs. 42 and 43, Plate 32, which may be regarded as combining a right and left pair of Rudge tricycles, as shown in plan in Fig. 76, Plate 45. The Grosvenor sociable—a combination of Fig. 30, Plate 27, with Fig. 40, Plate 31, which duplicates the single tricycle of the same name—has all the advantages and defects of the machine last mentioned, lacking its backward stability. The Royal Mail two-track tandem, Fig. 44, Plate 33, duplicates class C, as shown in Fig. 75, Plate 45, but without introducing any improvement in distribution of wheel load.

Many tandems are combinations of the two classes A and B, as shown in Fig. 74, Plate 45. The most notable are the Club tandem, Fig. 45, Plate 33; the Carver tandem, Fig. 46, Plate 34; and the Quadrant tandem, Fig. 47, Plate 34: in all of which the front small

wheel steers and the hind small wheel is a carrier only. The chief advantage of this combination is the reduction in dead weight as compared with most other four-wheeled convertible cycles; but the loads on the small wheels are as great or greater than in the single machines of classes A and B. One example of these combinations has been provided with a screw coupling between the frames, so arranged that the pilot and trailing wheels are lifted permanently out of the same plane with the driving wheels, and the riders can balance themselves and ride on three wheels only, as class A downhill, and as class B on a level and uphill: thus saving the friction of one wheel, and greatly reducing the load on the other. In a few of these combined A and B tandems, as with the Krao trailing frame for attachment behind tricycles of class B, Fig. 37, Plate 30, the hind wheel is increased in diameter to medium size, and is provided with driving gear worked by the rear rider. The total driving load is thus somewhat augmented.

A final class of four-wheeled cycles, shown in Fig. 77, Plate 45, might be called the double dicycle. By means of a swivel coupling, the larger wheels of any two tricycles of the A and B classes are combined, forming a machine which is comparable with Rucker's tandem bicycle in the perfection of its load distribution, since all the four wheels are large in diameter, and all are drivers and all steerers. The neatest combination of this kind, as shown in Fig. 48, Plate 35, and Fig. 77, Plate 45, is when a Cruiser and a Humber tricycle are conjoined by a special coupling-bar. Messrs. Marriott and Cooper's four-wheeled tandem for four riders consists of the dicycle parts of two tandems of classes A and B respectively, with their small wheels removed, and the main frames coupled by a universal joint. The ratio of dead load to passengers is thus greatly reduced, and with the absence of small-wheel friction great speed and safety may be obtained.

Some cycles have been made with five or more wheels. The most notable is Gibbons' arrangement, Fig. 49, Plate 35, in which a tricycle of class A with its small wheel retained is coupled in front of one of class B deprived of its small wheel.

Influence of Gradient and of Rider's Position.

It remains now to be considered how variation in gradient affects the distribution of the wheel load, and how the rider's position may be varied so as to retain on a gradient the same favourable distribution of load that has been arranged for a level.

In the bicycle shown in Fig. 63, Plate 42, it has been seen that a falling gradient of only 1 in 20 might seriously disturb the rider's stability, but that by leaning forwards uphill and backwards downhill he can maintain his centre of gravity in a suitable position with regard to the wheel base. But neither of these positions is so comfortable as the vertical position which the body assumes on a level. Bicycles have been designed by Mr. Strickland and Messrs. Licence and Downs in which the upper curved part of the backbone is telescopic, and can be lengthened or shortened by a rack and pinion or equivalent device. When lengthened, the saddle and handles are carried forwards, so that the rider is still vertical when riding uphill; and conversely, when shortened, he is in a correct position for riding downhill. Whether the seat can be readily shifted from full forwards to full backwards on crossing the crown of a hill remains to be seen; if not, the rider would be in a worse position than without the device.

In the safety bicycles, shown in Figs. 64, 65, 66, 68, and 69, Plates 42 and 43, the rider's weight is so well arranged over the wheel-base that he is in a stable position both up and down hill. But there remains the disadvantage that uphill the load on the small wheel is increased, with corresponding increase in the resistance to be overcome by the rider, who is already fully burdened by the work of lifting his own weight and that of the cycle. Downhill there is a tendency to slip off the seat forwards, unless foot-rests are used well in front of the pedals. In Mr. Phillips' paper, read at the Coventry meeting last October, was described the dwarf safety bicycle of Mr. F. Warner Jones, Fig. 55, Plate 38, in which the rider's position is altered by an adjustable frame in the same manner as in his Devon tricycle, Figs. 50 and 52, Plate 36. In the Kaiser safety bicycle, Fig. 12, Plate 19, the swinging seat-pillar provides the means of varying the rider's position

by a contrivance which is perfect in action and automatic in adjustment, and on any gradient instantly places the rider in the best position for utilising his strength.

Tricycles also with rigid frames are at a disadvantage from the cause above mentioned, when travelling on varying grades or against great resistance. In Fig. 51, Plate 36, is given a representation by no means greatly exaggerated of the awkward position assumed by many tricycle riders when working at high speed or against a wind resistance. It is true that nearly all tricycles are fitted with the ⅂-shaped pin or some similar device for shifting the position of the seat fore and aft. But in few of them can the shifting be managed whilst riding; and all that a rider can do is to average a sort of medium position to suit his comfort on a level, and up a steep gradient to rise from the saddle and stand wholly on the pedals, holding on by the handles. This can be done with tolerable convenience in tricycles of classes B, C, D; but in many of class A it is out of the question.

The "Club" sliding seat, Fig. 53, Plate 37, and also the "Matchless" sliding seat, Fig. 54, provide the means of varying the rider's position within certain limits whilst riding; but in comparison with the considerable forward movement made by the rider of a Salvo or Rudge tricycle when he stands on the pedals for working uphill, it will be seen that devices of this kind would be cumbersome if they provided for the same extent of forward movement; whilst no smaller extent will fully meet the rider's requirements. A more complete solution of the problem is afforded by the adjustable double frame of Mr. F. Warner Jones, Figs. 50 and 52, Plate 36, where the long range of adjustment is obtained by altering the position of the pedal shaft simultaneously with the movement of the saddle. Another device, designed by Messrs. Hurrell and Spence, enables the seat and pedals to be maintained in a constant position relatively to the vertical, by mounting the small leading wheel of class B on a hinged part of the frame, provided with shifting gear so that it can be raised or lowered by the rider on an up or down gradient, giving an

adjustment very similar in nature to that afforded by the double frame of Mr. Jones.

All these devices however have so far in common the defect that the alteration of the rider's position has to be effected by himself; each change of gradient requires an action on his part for releasing the seat, shifting it, and locking it again in its new position. The further improvement therefore required is to render the adjusting action automatic, so that a rider shall not be able to make the mistake of putting the adjustment in the wrong notch, but shall be almost compelled by the machine itself to take up a suitable position. This property is inherent in all the class of dicycles, which, having only a transverse line for wheel base, roll forwards or backwards without altering the perfect distribution of wheel load, and automatically place the rider in the very position aimed at by the devices already mentioned; and in addition effect small changes to suit little changes of ground not contemplated in the previous adjustments. Also by slightly swinging both feet forwards at the moment when the cranks are approaching their dead points, the train-arm action of the swinging frame and of the connecting gear carries the cranks over the dead points: so that, even when travelling slowly against heavy resistance or uphill, there is very much less danger than in rigid-framed cycles of sticking on the dead points. The result is that the dicycles, when once their proper riding is acquired, present a comfort and ease of propulsion excelled by no other cycle; and were it not for the defects previously pointed out, of deficiency in longitudinal stability and in brake power and in steering, together with the necessity for quite as much practice in riding as the bicycle requires, they would satisfy most of the heads of efficiency already enumerated.

Spinaway Tricycles.—The tricycle shown in Figs. 56 to 59, Plates 38 to 40, has been designed by the author to solve the problem of retaining this automatic adjustment of the rider's position between two equal lateral driving wheels, in combination with the advantages of the balance-geared front-steering tricycle of class

B or C. With this object the portions of the machine that do the carrying and driving are separated from those that do the steering and braking; and the two portions are placed on separate frames, which are connected by a hinge joint somewhat after the manner already described for enabling four-wheeled velocipedes to travel over irregular ground.

The driving and carrying portion consists of a pair of equal wheels at the ends of the same axle, on which is slung a frame F, carrying at the top the rider's seat S, Fig. 57, and at the bottom a cranked pedal-axle P, Fig. 58, connected with the main wheels by any convenient plan of balance driving. Thus far the machine would be only an imperfect dicycle, which could indeed be ridden, but is without any appliances for steering and braking.

The steering and braking apparatus consists of a small pilot wheel at the end of a frame or arm projecting forwards, Figs. 57 and 59, which may be connected with the dicycle frame at any convenient point by a hinge with horizontal axis, so that the vertical swing of the dicycle is not interfered with, while at the same time the front wheel can also rise and fall independently, somewhat after the manner provided for by Messrs. Hurrell and Spence's device. The front wheel may be steered by any usual arrangement of rack and pinion, bevil or link gear; but the author prefers a light steel-wire cord wrapping round pulleys, as being cleaner, lighter, and free from backlash and noise. The steering handle H is fixed on the steering frame G, and serves also as a convenient support for enabling an entirely inexperienced rider to retain his seat without previous practice. In addition the two frames F and G are connected by a spiral spring R, so as to steady the oscillations of the dicycle frame F and to give it a bias into the proper position for riding on a level. Foot-rests TT attached to the frames F and G permit the feet to be removed from the pedals when running downhill. The steering frame G serves also for the attachment of a powerful band-brake K acting upon both the driving wheels through the balance gear. When the hinge of the two frames F and G is made co-axial with the main axle, the sudden application of the brake has no tendency whatever to lock the entire frame to the axis, as it has in previous dicycles; but if not made co-axial, then in this machine

there are the usual defects of dicycle brakes, unless the brake levers are worked from the steering frame through a parallel motion or equivalent device. A second or left handle N for working the brake K may be attached either to the dicycle frame F, or to an arm on the steering frame G; in the latter case the same arm also serves conveniently for the attachment of the brake mechanism and of baggage clips.

In the Spinaway tricycle it will thus be seen that the rider's whole weight is balanced on the main axle, and that the load on the ground at the steering wheel is reduced to merely the weight of the wheel itself and of the front part of its frame; and this weight is found to give ample adhesion for ordinary steering. In emergencies and on slippery roads, the load on the steering wheel can be instantly increased by the rider simply leaning on the handles H and L; and conversely, if the steering wheel sticks in a rut or a tram groove, it can be lifted out by the same handles. A secondary advantage, of great value in touring through rough country, is that the steering wheel can jolt over stones or rough paving without communicating any jar or vibration to the seat and pedals.

This tricycle is very readily conformable with the two-track class C, while it is free from the disadvantages attending rigid-framed tricycles of that kind. For as the load is always balanced on the main wheels, there is no sensible difference of forward stability towards either side; and the connecting hinge and spring do away with the necessity for heavy pieces to stand the stresses which usually occur in two-track frames at the connection of the backbone with the pedal-frame. It has also been made with central gear and bicycle steering, and as a sociable tricycle of class B; and has been found very advantageous for comfortable riding and touring over all sorts of roads. The balanced frame has also been applied to the Rudge tricycle, class D, with great advantage and reduction of vibration.

Kaiser Cycles.—In these cycles the position of the rider is automatically adjusted to the gradient by the use of a swinging seat-pillar with a spring balance, as in the Kaiser safety bicycle already described on page 137. The same method may be applied to

tricycles of any class; and in Fig. 60, Plate 41, is shown the most complete development in the tandem tricycle, which has a rigid frame of class B, giving great stability under the application of the brake; whilst the swinging seat-pillars enable the riders to keep their weight nearly balanced on the main axle, and thus reduce the load and resistance of the pilot wheel to a minimum; and the pilot wheel is also made rather large for easier running on rough roads. Either rider can steer or apply the brake; and by removing a few screws the hind seat and gear can be detached, leaving a perfect tricycle for a single rider.

In Tables I–III appended are given the leading measurements of the principal cycles which have now been mentioned, together with an estimate of the probable load on each wheel when running at a considerable speed. It would of course be impossible actually to weigh the wheel loads whilst in motion, except by elaborate and costly apparatus; but the assumption has been made that in average travelling one third of the rider's weight remains on the seat and the other two thirds are transferred to the pedal axle. In several cases this calculation has been verified by comparing it with the actual loads when the riders, though at rest, took special pains to assimilate their position to that assumed when in motion.

The most interesting columns in these Tables are those giving the load per inch of diameter on each wheel. The whole of the examples were roadster cycles, and were not specially chosen for lightness of construction. Throughout nearly the whole of Table II it will be noticed that in these tricycles for a single rider there is a striking uniformity of load per inch, namely from 2 to $2\frac{1}{2}$ lbs.; and this is almost independent of the size of wheel. In Table I the bicycle driving wheels are seen to be loaded to nearly double what the tricycle wheels carry; and the same tendency to higher wheel-loads is noticed also in the cycles for two riders in Table III. The exceptional cases are the small wheels of the Rudge tricycle and tandem, which carry up to 4 and 6 lbs. per inch; and the driving wheel of the Rucker dwarf tandem bicycle, which carries more than 9 lbs. per inch of diameter. On the other hand, by

means of the flexible balanced frame, the load on the pilot wheel of the Spinaway tricycle is reduced to less than 1 lb. per inch in ordinary running; and it is difficult to put on as much as 2 lbs. per inch, even by leaning forwards on the handles.

In the compilation of these statistics the author has been greatly aided by very numerous friends and manufacturers, who have freely lent machines for the purpose of weighing and measuring; and he wishes to express his particular obligations to Mr. Sidney Lee, Mr. S. Golder, Mr. James Taylor, and Professor Poynting, who have also personally assisted his experiments.

TABLE I. (*see continuation on opposite page*)

Dimensions of Two-Wheeled Cycles for one rider.

	Class and Name of Cycle, and name of maker.	Reference to Illustrations. *See* Plates 14–43.	Diameters of Wheels. Front.	Diameters of Wheels. Driving.	Diameters of Wheels. Rear.	Wheel Base. Length fore & aft of driving wheels. Fore.	Wheel Base. Length fore & aft of driving wheels. Aft.	Wheel Base. Width.	Height of Saddle or Seat.
	BICYCLES.	Figs.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
	Hobby Horse Goy.	1 61	29	...	27	45		...	...
Front Driving.	Roadster Rudge and Co.	3 63	...	52	17	...	31	...	54
Front Driving.	'Xtraordinary, Safety. Singer and Co.	4 64	...	44	22	...	33	...	46
Front Driving.	Facile, Safety Ellis and Co.	5 65	...	40	22	...	31	...	42
Front Driving.	Challenge, Safety Singer and Co.	6 66	...	38	22	...	34½	...	40
Front Driving.	Kangaroo, Safety Hillman Herbert & Cooper.	7 67	...	36	21	...	29	...	41
Rear Driving.	American Star H. H. Smith Machine Co.	9	21	51	...	34	...	...	55
Rear Driving.	B.S.A., Safety Birm. Small Arms Co.	8	20	32	...	35	...	...	41
Rear Driving.	Humber, Safety Humber and Co.	10 68	18	30	...	33	...	...	39
Rear Driving.	Swing-Frame Safety F. W. Jones.	55	22	36	...	33	...	...	42
Rear Driving.	Rover, Safety Starley and Sutton.	11 69	36	30	...	46	...	...	40
Rear Driving.	Kaiser Safety Griffiths and Co.	12	33	33	...	43	...	...	40
	DICYCLE.								
	Otto Birm. Small Arms Co.	13	...	54 54	...	...	...	31½	36

The weight of the cycle empty includes saddle or seat, spring, mud-guards, foot-rests, &c., when provided; but not lamp, bell, or luggage.

The running loads, including a 12-stone rider = 168 lbs., are estimated for each wheel separately, when there is 56 lbs. on the saddle and 56 lbs. on each pedal.

(*continued from opposite page*) TABLE I.

Distribution of Wheel Load in Two-Wheeled Cycles for one rider.

Weight of Cycle empty.				Estimated Running Loads, including 12-stone rider.						Percentage of Saddle Load on each wheel.		
	Distribution on wheels.			Total on each wheel.			Per inch of diameter.					
Total Weight.	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	P.c.	P.c.	P.c.
53	28	...	25	112	...	109	3·9	...	4·1	50	...	50
40	...	33	7	...	183	25	...	3·5	1·5	...	68	32
50	...	39	11	...	137	81	...	3·1	3·7	...	52	48
46	...	36	10	...	168	46	...	4·2	2·1	...	68	32
55	...	45	10	...	160	63	...	4·2	2·9	...	44	56
50	...	40	10	...	179	39	...	5·0	1·8	...	62	38
63	13	50	...	27	204	...	1·3	4·0	...	7	93	...
48	19	29	...	86	130	...	4·3	4·0	...	20	80	...
43	18	25	...	89	122	...	4·5	4·1	...	30	70	...
62	17	45	...	50	180	...	2·3	5·0	...	0 to 21	100 to 79	*
52	22	30	...	84	136	...	2·3	4·9	...	30	70	...
52	22	30	...	54 to 99	166 to 121	...	1·6 to 3·0	5·0 to 3·7	...	24 to 45	76 to 55	†
80	...	40 / 40	...	...	124 / 124	...	...	2·4 / 2·4	...	...	50 / 50	...

The percentage of saddle load on each wheel is estimated simply in the inverse ratio of the longitudinal subdivision of the wheel-base fore and aft of the centre of the saddle in plan.

* Varied mechanically by rider. † Varied automatically.

TABLE II. (*see continuation on opposite page*)

Dimensions of Tricycles for one rider.

Name and Class of Tricycle, and name of maker.	Reference to Illustrations. *See* Plates 20 to 44.	Diameters of Wheels.			Wheel Base.			Height of Saddle or Seat.
		Front.	Driving.	Rear.	Length fore & aft of driving wheels.		Width.	
					Fore.	Aft.		
TRICYCLES.	Figs.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Meteor Rear-Steerer A Starley and Sutton.	14 70	40	40	17	...	38	30	36
Humber . . . A Humber and Co.	16 70	...	44 44	18	...	32	33	40
Cruiser . . . . A Hillman and Co.	17 70	...	44 44	20	...	36	33	40
Quadrant No. 1 . A Lloyd Brothers.	22 70	...	46 46	34	...	33	33	37
Monarch . . . A Pitt and Co.	18 70	...	40 40	18	...	43	32	37
Emperor . . . A Pitt and Co.	24 70	42 42	30	...	26	...	28	38
Salvo . . . . B Starley Brothers.	25 71	17	46 46	...	31	...	31	36
Sparkbrook. . . B Sparkbrook Mfg. Co.	26 71	20	48 48	...	33	....	31	36
Quadrant No. 8 . B Lloyd Brothers.	27 71	26	40 40	...	37	...	33	39
Cripper . . . . B Humber and Co.	28 71	18	40 40	...	31	...	31	37
Spinaway (cent. gear) B Griffiths and Co.		20	44 44	...	33	...	32	39
Devon . . . . B T. Smith and Sons.	50 52	20	48 48	...	32	...	33	38
Spinaway (2-track) C Griffiths and Co.	56 to 59	20	48 48	...	34	...	32	38
Royal Mail. . . C Royal Machine Mfg. Co.	29 72	18	44 44	...	36	...	29	35
Coventry Rotary . D Rudge and Co.	31 73	20	48	20	30	30	25	38

The weight of the cycle empty includes saddle or seat, spring, mud-guards, foot-rests, &c., when provided; but not lamp, bell, or luggage.

The running loads, including a 12-stone rider = 168 lbs., are estimated for each wheel separately, when there is 56 lbs. on the saddle and 56 lbs. on each pedal.

(*continued from opposite page*) TABLE II.

Distribution of Wheel Load in Tricycles for one rider.

Weight of Cycle empty.				Estimated Running Loads, including 12-stone rider.						Percentage of Saddle Load on each wheel.		
	Distribution on wheels.			Total on each wheel.			Per inch of diameter.					
Total Weight.	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	P.c.	P.c.	P.c.
93	34	34	25	108	108	45	2·7	2·7	2·7	30	30	40
72	....	32 29	11	...	90 86	64	...	2·0 2·0	3·7	...	50	50
77	...	34 29	14	...	97 93	55	...	2·2 2·1	2·7	...	58	42
91	....	33 33	25	...	101 101	57	...	2·2 2·2	1·7	...	60	40
77	....	31 31	15	...	108 108	29	...	2·7 2·7	1·7	...	75	25
80	28 28	24	...	78 78	92	...	1·8 1·8	3·4	...	50	50	...
77	11	32 34	...	43	100 102	...	2·6	2·2 2·2	...	5	95	...
98	14	42 42	...	46	110 110	...	2·3	2·3 2·3	...	6	94	...
67	21	23 23	...	67	84 84	...	2·6	2·1 2·1	...	21	79	...
64	18	21 25	...	72	78 82	...	4·1	2·0 2·0	...	13	87	...
68	12	28 28	...	16	110 110	...	0·8	2·5 2·5	...	Varied automatically.		
98	18 to 12	40 to 43	...	54 to 44	106 to 111	...	2·5to 2·0	2·1 2·1	...	Varied mechanically by rider.		
78	10	34 34	...	16	115 115	...	0·8	2·4 2·4	...	Varied automatically.		
94	18	38 38	...	50	106 106	...	2·7	2·4 2·4	...	8	92	...
75	23	34	18	82	101	60	4·2	2·1	3·1	32	40	28

The percentage of saddle load on each wheel is estimated simply in the inverse ratio of the longitudinal subdivision of the wheel-base fore and aft of the centre of the saddle in plan.

TABLE III. (*see continuation on opposite page*)

Dimensions of Cycles for two riders.

Name and Class of Cycle, and name of maker.	Reference to Illustrations. *See* Plates 29 to 45.	Diameters of Wheels.			Wheel Base.			Height of Saddle or Seat.
					Length fore & aft of driving wheels.		Width.	
		Front.	Driving.	Rear.	Fore.	Aft.		
SOCIABLES.	Figs.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.	Ins.
Club . . . . B Coventry Machinists' Co.	71	18	46 46	...	37	...	54	37 40
Coventry Convertible D Rudge and Co. D	42 76	20	48 48	20	30	30	50	38 40
Spinaway . . . B Griffiths and Co.		24	48 48	...	48	...	54	38
TANDEMS.								
Rucker Dwarf Bicycle Rucker and Co.	34	...	38	20	...	32	...	47 51
Humber . . . . A Humber and Co.	36 70	...	44 44	18	...	34	33½	36 38
Centaur Front-Steerer Centaur Cycle Co. B	35 71	18	48 48	...	44	...	33	39 40
Kaiser . . . . B Griffiths and Co.	60	24	44 44	...	40	...	32	...
Carver . . . . A B James Carver.	46 74	18	40 40	18	32	32	33	36 41
Club . . . . A B Coventry Machinists' Co.	45 74	17	46 46	18	34	35	33	37 40
Quadrant . . . A B Lloyd Brothers.	47 74	26	40 40	26	38	40	33	40 36
Rotary . . . . D Rudge and Co.	41 73	20	48	20	32	32	27	42 42
CARRIER.								
Despatch . . . . Starley and Sutton.	39	20	40 40	...	55	...	31	38

The weight of the cycle empty includes saddle or seat, spring, mud-guards, foot-rests, &c., when provided; but not lamp, bell, or luggage.

The running loads, including a 10-stone and a 12-stone rider = 308 lbs., are estimated for each wheel separately, as in Tables I and II, supposing one-third of the weight of each rider to be on his saddle and one-third on each of his pedals.

(*continued from opposite page*) TABLE III.

Distribution of Wheel Load in Cycles for two riders.

Weight of Cycle empty.				Estimated Running Loads, including 10-stone and 12-stone riders.						Percentage of Saddle Load on each wheel.		
Total Weight.	Distribution on wheels.			Total on each wheel.			Per inch of diameter.					
	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.	Front.	Driving.	Rear.
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	P.c.	P.c.	P.c.
150	29	54 67	...	108	166 184	...	5·8	3·8 4·2	...	9	91	...
120	31	30 33	26	140	86 101	101	7·0	1·8 2·1	5·0	32	18 22	28
122	15	52 55	...	29	194 207	...	1·2	4·0 4·3	...	Varied automatically.		
76	...	65	11	...	334	50	...	9·3	2·5	...	70	30
99	...	49 44	6	...	193 187	27	...	4·4 4·2	1·5	...	77	23
146	22	57 67	...	53	196 205	...	2·9	4·1 4·3	...	10	90	...
104	...	...	...	...	...	...	...	...	...	Varied automatically.		
116	17	45 43	11	58	157 160	49	3·3	3·9 4·0	2·5	10	70	20
130	18	48 48	16	57	148 148	85	3·3	3·2 3·2	4·7	12	66	22
119	22	37 37	23	65	147 147	68	2·5	3·7 3·7	2·6	14	72	14
115	32	53	30	123	178	122	6·1	3·7	6·1	25	40	35
106	26	41	39	103	107	104	5·2	2·7	2·6	34	33	33

The percentage of saddle load on each wheel is estimated simply in the inverse ratio of the longitudinal subdivision of the wheel-base fore and aft of the centre of gravity of the combined saddle-loads in plan.

Discussion.

Mr. GRIFFITHS exhibited specimens of the Kaiser bicycle and the Spinaway tricycle described in the paper; and illustrated the automatic adjustment of the rider's seat in each machine.

He mentioned that this paper had been written originally six months ago, for reading at the Coventry Meeting last October; but through want of time on that occasion and again at the subsequent meeting the reading had been postponed. During the interval which had elapsed there had been considerable slackness in the cycle industry as well as in trade generally; and those who had followed the course of recent cycle manufacture would have noticed that during the winter nearly all the makers had been producing new patterns, in which the results of studies very similar to his own had been carried out, by increasing the size of the pilot wheels and effecting other improvements such as had been suggested in the paper. Possibly therefore the paper itself might have had something to do with the progress realised; but at any rate this progress was a very striking confirmation of his own views as set forth in the paper. Consequently if he had now had to draw up the tables afresh, from the experience of the last six months, they would have included some examples showing a better distribution of load than those actually given; but though not strictly accurate throughout for the present cycles, the tables were nevertheless in the main fairly representative of the present period. If any makers were now able to furnish revised figures of more recent date, he should be glad to receive them for adding to the fulness of the records.

Mr. C. VERNON BOYS had followed with much interest the able paper by Mr. Griffiths. The statistics furnished in it were undoubtedly of great value; the trouble of collecting so vast a mass of material, such as weights and dimensions, was so great that all interested he was sure felt very much indebted to the author for having accomplished so useful and laborious a task. In so far as

principles were concerned, he was not prepared to agree with all that had been said in the paper; but it was rather in incidental points than in essential principles that he failed to follow the author.

An unimportant matter, to which he wished to refer, was the introduction of the word "dicycle." There was of course no objection whatever to the word itself; but it was a question whether the public would ever learn to discriminate between bicycle and dicycle. Moreover there was no reason why the word bicycle should belong to the long machine and dicycle to the wide one, unless it were—though he could hardly think that this would be considered a good reason—that the design of the wide kind, hitherto known as the Otto, being derived from mechanical principles the most perfect, should be called by a name having a correct derivation, and not by a mongrel word like bicycle.

The classification of tricycles in page 139 was good, in that it adapted itself to the title of the paper; but he thought it was practically a mistake to include under the same group both the Humber and the other rear-steerers of class A. It had been pointed out on page 130 that it was really the position of the driving wheels rather than of the steering wheel which affected the character of the machine, and that the designation front-steering or rear-steering simply implied that the front or the rear wheel could be swivelled with respect to the frame of the machine. Now there was the utmost difference between the effect of the swivelling in the two cases that were included in class A. In each case the swivelling could be effected with certainty, and in each case the machine would travel in the direction in which the front wheels lay, because nearly the whole weight was on them. Except when well-weighted, as in the Rover, a rear-steering wheel was not capable of suddenly slewing round with certainty and in the intended direction the front-wheels and frame and rider. The erratic character of the ordinary rear-steerer was well known; but in the Humber the rider by his inertia could compel the front wheels to swivel in either direction, as desired.

(Mr. C. Vernon Boys.)

This introduction of dynamical considerations led to the real point of importance, namely the variation of the load according to the driving action. That this important matter had not been overlooked was evident in many parts of the paper, especially at the bottom of page 133; but it did not seem to be clearly explained, and he thought due allowance had not been made for it in the author's theory of stability. The distribution of the wheel load would of course be affected both by the gradient and by the rider's position, as was explained in the paper, and would therefore vary from time to time; and whatever position the rider might assume, and whatever gradient the machine might be on, the distribution of wheel load could be easily found, provided the rider were not driving either forwards or backwards and were not applying the brake. Mere statical considerations would under those conditions be sufficient to determine the distribution. But as soon as the rider drove or stopped the machine, dynamical considerations presented themselves; and it was these which were rather referred to than explained in the paper. If possible he should like to put them in a clearer light, as there was much misapprehension on the subject. When the rider applied force to either of the treadles and so tended to turn the main axle, or when by the brake he tended to stop the motion of the main axle, the rider and the frame combined were in effect one body, and the axle was another, and the force between them was of the nature of a couple. Whatever turning force was applied to the axle, an equal and opposite turning force re-acted on the frame, thereby altering of course the distribution of wheel load. For example, taking 31 inches as the wheel-base of a bicycle and 5 inches as the length of a crank, if the rider pressed either treadle with a force of 180 lbs. at right angles to its length, the couple would be 900 inch-lbs., which was equivalent to 29 lbs. acting on an arm of 31 inches: so that 29 lbs. was the increased weight on the hind wheel if the rider was forward treadling, or on the front wheel if he was back treadling. That would be an increase over what the weight would be if the rider and machine were to assume precisely the same position, but without the application of the driving force of 180 lbs. If the position was such that without this force there was not so

much as 29 lbs. on the rear wheel, then back treadling to the extent indicated, or an equal backward pull with the brake—no matter which,—would raise the hind wheel from the ground. The same considerations applied exactly to machines with gearing, in which it was of no consequence how the turning force was produced, whether by a strong push on a high-geared machine or by a less strong push on a low-geared machine. Whatever couple was produced at the driving axle as the result of the action of the rider or of the brake, that couple would always act on the frame and so disturb the load distribution in the manner already shown. This was the explanation of the fault noticed in the experimental bicycle referred to in page 135, in which the rider was placed further back than was usual, and was supplied with the means of employing great leverage for driving; not only was there thus less weight on the driving wheel to begin with, but then by being able to produce an excessive turning force the rider still further reduced the weight upon it; hence its skidding. The explanation given in page 136 as to the stability resulting from a hind-wheel brake was imperfect; but these considerations showed that as the brake action was increased the weight on the rear wheel was diminished, until the point of skidding was reached, which did not require much brake force. Thus a Cripper rear-driving tricycle, Fig. 28, Plate 26, which had so much weight on the drivers that skidding would seem almost impossible, had that weight so greatly reduced by the brake that skidding easily occurred. More brake power could not then be applied, and hence the stability. This action would seem to have been misunderstood in the endeavour made in page 140 to account for the defect of the familiar single-driving rear-steerer in class A; for it was there said that the effect of driving was to diminish the weight on the rear-steering wheel, whereas the action was directly the reverse. The real reason why such a machine could not be driven with more power was that the driving here acted like a pull on one side, tending to slew the machine round; and as the pace increased, the hind wheel jumped more at every obstacle, and therefore failed to hold the machine straight when its tendency to swerve was the greatest. As correctly stated on page 143 the weight on the front wheel of a Cripper

(Mr. C. Vernon Boys.)

was reduced by driving; but this was wholly the result of the lifting action under consideration, and had nothing whatever to do with the placing of the handles. However the handles might be placed, the same driving power exerted by a rider in the same position would result in the same reduction of weight on the front wheel. The supposition on which the columns of running loads in the tables were calculated—namely that two-thirds of the rider's weight was on the pedal axle—though possibly correct in itself, might be feared, in view of the variation of load in driving, lead to incorrect figures, though not necessarily to any great extent. The weight stated might be on the pedal axle; but according as the rider was treadling forwards or backwards there would be more than the weight stated on the hind wheel in the one case, or on the front wheel in the other.

As to the theory of fore and aft stability, page 137—according to which, when the path of the treadles was entirely within the shaded triangle, as in Figs. 65, 68, and 69, Plate 43, stability existed to such an extent that no modification of the pedal pressures could reduce the hind-wheel load below zero—it was not plain whether this was put forward as a true theory depending on any principle of mechanics, or whether it was merely a statement of something that happened to be pretty nearly true in existing machines. It might happen that practically it was generally true; but it certainly was not necessarily true. There was in fact an exception in the case of the Facile, in which if a rider were strong enough he could raise the hind wheel by back pedalling, as of course he could equally well do by violent application of the brake. It made no difference whatever whether the path of the treadles was inside or outside the triangle of stability: by sufficient force on the treadles the rear wheel could be raised by back pedalling in a front-driver, or the front wheel by forward pedalling in a rear-driver.

With regard to lateral stability, there was no necessity for the distinction on page 140 between high and low velocities in connection with the lateral stability of the Humber tricycle when running round curves: at all speeds the stability would be greater, on account of the rider being nearer the inner wheel, than it would

be if he were kept midway between the wheels; but it did not follow that this stability would be positive. Reference was made on page 136 to the extra gyroscopic stability of the larger front wheel in the Rover safety bicycle: of which machine he was glad to see that the author spoke so well, as he imagined it to be the most perfect of the small safety bicycles. This gyroscopic action of wheels had an effect not always recognised: in bicycles it increased the lateral stability, whereas in tricycles and dicycles it reduced the stability. As illustrated by the little perambulator wheel which he now exhibited, and to which a high speed of rotation was imparted by hand, it was seen that, if the rider on a bicycle wheel tended to fall sideways, the effect of the gyroscopic action was to slew the wheel round in the direction in which he was falling, and thus to save him; thus the wheel itself, as was well known, would to a certain extent keep the rider upright. But the result was quite different in the case of tricycles or dicycles; in these the gyroscopic action of the wheels in running round a corner was always such as tended to make the machine upset towards the outside of the curve. Now if a fly-wheel revolving rapidly the reverse way to the wheels of the machine were carried on a tricycle, then the lateral stability would be increased; and if the fly-wheel revolved fast enough or had sufficient moment of inertia, the lateral stability could even be increased beyond mathematical infinity so that the tricycle would capsize towards the inside instead of towards the outside of the curve it was describing. He did not mean to suggest that tricycles should carry fly-wheels mounted upon them for the sake of stability; but such wheels might some day be carried on them for another purpose, though he hardly expected to see this done just yet. Whenever tricycles came to be driven by electro-motors, care would have to be taken to run the motor the reverse way to the cycle wheels. In view of the high speed at which an electro-motor must run, and the great moment of inertia of its armature, there was no doubt that the lateral stability would be considerably modified by its direction of rotation. If it ran the same way as the cycle wheels, there would be an aggravated tendency to capsize on curves; whereas if it ran the opposite way it would tend to hold the tricycle upright in running round

(Mr. C. Vernon Boys.)
curves. The whole of this part of the subject, but especially the variation of longitudinal stability with the driving or stopping, he considered to be of great importance, and among the majority of cyclists to be entirely misunderstood. Those who imagined that mere statical considerations were sufficient to account for what happened on a moving machine—like electricians who failed to allow for the effects of induction, which corresponded very nearly with inertia in mechanics—were apt to be led astray and to expect things to happen which were impossible.

On the subject of the Otto dicycle he wished merely to offer a correction upon some minor points in page 138 of the paper. In going round a curve both of the wheels drove, but the outer wheel more than the inner. Instead of being deficient in steering (page 151), the Otto was of all machines the most perfect steerer; but the rider must thoroughly understand it, or the deficiency would be in him and not in the machine, and it would go the wrong way. Thoroughly to understand the Otto required more practice than was necessary to ride a bicycle. In connection with central-geared dicycles it was stated in the paper (page 138) that "a positive gearing is yet wanted which shall drive both wheels of a dicycle at any determinate and variable differential speed." As this want had so often been expressed, it might be well to point out that such a gear was nothing more nor less than an integrating machine; and those who had any acquaintance with that subject, which was one to which he had himself given some attention, would know to what extent integrators were available for the purpose. There were only two he believed which were capable of transmitting power; and neither of these was practically available.

In the cycles designed by the author, which practically formed the climax of his paper, the endeavour had been made to arrange both a bicycle and a tricycle wherein the advantages of the automatic swing-frame of the Otto should be retained, without the difficulty which that machine presented to the beginner. The ingenuity displayed by the author was certainly much to be admired; and he was inclined to believe that the swinging frame in the Spinaway and the rocking pillar in the Kaiser were very advantageous. But what

he was not sure of was that no evil could result from the helical retaining spring, which must be extended and allowed to contract at every oscillation of the seat. Not having yet had an opportunity of trying either of these machines, he did not know how this spring really acted; and no one without trying could form an opinion whether the swing constrained by the spring was the same as the free swing in the Otto. With the comfort given by the oscillation of this swing frame he was of course sufficiently familiar. The question was whether the author's cycles retained the disadvantages of the tricycle and the difficulty of the Otto; or whether they were machines which retained the advantages of the Otto, while at the same time anyone could ride them at once with comfort and safety.

Mr. W. T. SHAW said the size of wheels for cycles was a subject to which he had paid some attention a few years ago; and upon mechanical grounds he advocated the superiority of moderately large wheels, inasmuch as the road resistance varied * inversely as the square root of the wheel diameter: that is, a 4-ft. wheel would have only half the resistance of a 1-ft. wheel in travelling along the same road and under the same load, whatever the speed might be. As a matter of course, if the road resistance were very small indeed, then the saving effected by the use of large wheels as against small wheels must be insignificant. But if the road resistance were great, then the saving by the use of a large wheel was important. This principle being conceded, he was led to impugn slightly what seemed to be the distribution of load recommended in the paper, namely that the rider's entire weight should be thrown as far as possible upon the large wheels, and that only just so much should be left upon the pilot wheel as would enable it to do the steering. On the contrary he was himself rather inclined to think that the three wheels in a tricycle should be less unequally loaded with the rider's weight, and the steering wheel should be made large enough to take its due proportion. In some of the machines now so much in vogue, it

* "The Construction of Roads and Streets," by Henry Law and D. K. Clark, 1877, page 295.

(Mr. W. T. Shaw.)

appeared to him that this principle had not been sufficiently kept in view. On the other hand, in many Cripper tricycles now in use, far too much weight was thrown on the small pilot wheel in front; and he thought it would be highly important in its practical advantages to riders if the load on tricycles were so arranged that each of the wheels should bear its fair proportion of the weight.

In reference to Mr. Boys' remarks about the application of pressure to the pedals and to the brake, he did not understand whether those remarks were intended to apply exclusively to cycles in motion. If the brake were applied to a cycle in motion, the rider's momentum would of course tend to carry him forwards, and to lift the rear wheel; and he should be glad to know whether this was the action to which Mr. Boys' remarks had reference.

Mr. Boys said his previous remarks applied equally to cycles at rest and to cycles in motion. When a cycle was moving forwards, it seemed very clear that what he had said about the distribution of the load was true: but when at rest, it was not by any means so clear that the same must be true. Indeed it became very puzzling to see how the downward pressure of the foot on one of the pedals could tend to tip up the front or hind wheel. But the difficulty would be removed if it was borne in mind that the rim of the driving wheel, acting on the ground, gave rise to a horizontal force not passing through the centre of gravity of the machine and rider. If the whole cycle were to be pushed back rapidly by a force thus acting below the centre of gravity, the hinder portion would of course tend to tip up; and the reverse would be the case with a forward pulling force; and this was perhaps the easiest way of expressing roughly what he had previously been stating more precisely. It made no difference whether the machine was at rest or in motion.

As to the brake, supposing that any cycle were being driven forwards, the effect of the driving force was to diminish the weight on the fore part of the machine, and to increase the weight on the hind part, as compared with the weight that there would be on either part if the rider and the machine were in exactly the same position relatively to each other, but without the application of the

driving force. The application of driving force tended to raise the front wheel and lower the hind wheel, as every rider of a front-steerer knew; for if he tried to drive very hard, he could not keep the front wheel down. Conversely, if he were back-treadling, he increased the weight on the front wheel and diminished it on the hind wheel, as every rider of a rear-steerer knew; for then in back-treadling violently he could not keep the hind wheel down, and consequently could not keep the machine running in any particular direction. Now if the same retarding action were produced by the brake that was being produced by the rider's muscular effort in back-treadling, absolutely the same effect must be produced on the distribution of the wheel load. The rider and the frame were together acting as one body, and they were acting on the axle of the wheels as on a separate body jointed to them, the force being exerted by the one body upon the other. If any kind of force, whether a direct-acting force or a couple, were applied by one of these to the other, then, since action and re-action were equal and opposite, the first body would itself be subject to an equal and opposite force. If the rider of a tricycle or a bicycle going forwards caused a certain diminution of speed by back-treadling, that is by applying a certain definite force, the exact difference in the loads on the front and rear wheels produced by the back-treadling could be calculated according to the method he had already shown. If the machine were retarded to the same extent by means of the brake, instead of by back-treadling, absolutely the same difference of load would be produced; and therefore nothing whatever was gained in stability by stopping a cycle by back-treadling in comparison with stopping it by the brake, provided of course that the position of the rider remained the same. Indeed—since the brake acted uniformly during the whole of the revolution, while the feet acted in a manner harmonic in character—although the average distribution would be the same in the two cases, yet greater variations in certain parts of the revolution would be caused by the feet than in any part by the brake. It was commonly imagined that, when stopping by back-treadling, the point of the application of the weight was made lower, or otherwise altered in such a way that the cycle was rendered more

(Mr. C. Vernon Boys.)

stable. Any such notion was really just as ridiculous as the absurd idea of children that when being driven in a carriage they could help it along by pushing forward in front with their feet.

Mr. L. W. MARSLAND mentioned that within the past fortnight he had made his first attempt at cycling, and had found very little difficulty in riding the Spinaway tricycle; but whether this machine was more easy or more difficult to work than others he could not say, as he had not yet tried any other machine. His experience had been a pleasant one, excepting only on a solitary occasion when he happened to get among a lot of vehicles. He had not found any difficulty in adapting his position to the gradient, according to whether he was going up or down hill; no attention indeed was required from the rider in this respect, as the swinging seat adapted itself automatically, swinging the body forwards up hill and backwards down hill, and enabling the rider to preserve an upright position on all gradients. His own first ride had been for a distance of nearly fourteen miles, the latter half of which was accomplished in an hour and a quarter.

Mr. WILLIAM SOPER thought the very important subject of the distribution of the wheel load in cycles might well be considered in relation to two different objects:—firstly with a view to securing the stability of the machine and the safety of the rider; and secondly with a view to ease of propulsion. The latter having been more fully dealt with in the paper, he would offer a few remarks on the question of stability. Passing by the monocycle as possessing so little stability that it was not prudent for an ordinary rider to risk his life upon it, the bicycle was a machine which for ease of propulsion had never been surpassed, but which in its old and dangerous form had such a small amount of stability that many who would be riders never attempted to mount it. Without endeavouring to prove that the modification of form necessary to secure the rider's safety would not in any way affect the case of propulsion which was the great charm of the bicycle, he would simply say that the consequent loss of power would be very slight indeed, if any,

and would be far more than counterbalanced by the satisfaction the rider would enjoy in knowing that he was not likely to be thrown over the front wheel. The conclusion at which he had himself arrived, as the result of practical trials made during many years past, was that in order to provide for the rider's safety upon a bicycle which might be driven at 15 or even 20 miles per hour, and at that speed might suddenly require to be pulled up in as short a distance as possible, it was absolutely requisite that the machine should be provided with a wheel placed so far in front, that if a line were drawn from the centre of the rider's body at an angle of not less than 40 degrees forwards from the vertical, the axle of the front wheel should be in advance of that line. On this point he differed from the representation given in the paper, where a triangle of stability was constructed by drawing lines from the extremities of the wheel-base to an apex situated only just over the saddle. The proper way of estimating the stability—taking for instance the bone-shaker in Fig. 62, Plate 42—would in his opinion be to draw the base of the triangle from axle to axle of the two wheels, and to put the apex at about the centre of the rider's body, which would be at some height above the saddle. In explanation of the reason why the front wheel should be mounted so far in advance as he had indicated, it should be borne in mind that, so long as the machine was stationary, the pressure of the rider's weight was wholly in the vertical direction; but as soon as the machine began to move forwards, the direction of the pressure, or the resultant line of thrust, would also begin to incline forwards in proportion to the speed attained, until at 20 miles an hour the line of thrust would be near an angle of 40 degrees from the vertical. It was therefore necessary that the axle of the front wheel should be in advance of this line, so that it might offer a reliable resistance to the heavy blow which would come upon the machine in the line of thrust whenever at a high speed the brake was suddenly applied. According to this view it would at once be seen from Fig. 69, Plate 43, that the Rover as there represented would be a very safe bicycle. It unquestionably provided for the rider's safety according to the principle now mentioned, namely that he should be so far in rear of the front wheel

(Mr. William Soper.)

that the line of thrust should never pass above the axle of the front wheel. In order that the rider might sit sufficiently in rear of the front axle of a bicycle to ensure his safety, it was desirable that the front wheel should be made smaller than in the ordinary bicycle, and the rear wheel larger, because much more of the weight of the rider would be carried by the rear wheel, as in the Rover, Fig. 11, Plate 19, and the Kaiser, Fig. 12. In fact the distribution of wheel load in a well-constructed safety bicycle should be about equal, or in other words the rider should be mounted midway between the two wheels.

In considering the proper distribution of wheel load in a tricycle, it would be well to settle upon the best form for constructing the machine according to the classification mentioned in page 139 of the paper; and as the defects of the tricycles in classes C and D appeared so manifest to himself, he would at once turn to class A, in which the base of the wheel triangle was forwards. These tricycles had for some years past been very popular; but it had gradually been found that for the rider's safety a great deal too much of the weight had to be put upon the rear wheel. They had therefore to a considerable extent been discarded in favour of class B: which confirmed the opinion he had held for some thirty years past, that the proper way to construct a tricycle was with the apex of the wheel triangle in front, because on that plan there was greater convenience for putting the rider in a position of safety, by placing the front axle in advance of the line of thrust, as already explained in regard to bicycles. A greater proportion of the rider's weight would then be carried by the two rear wheels, by which also any undue amount of oscillation from side to side would be prevented. It was on these principles that he had produced in 1880 the tricycle known as the Berkshire, in which the saddle was far enough in rear of the front wheel of 2 feet diameter to prevent the rider from being thrown forwards, and sufficiently in front of the main axle to prevent him from falling backwards. If in the Kaiser tandem tricycle, shown in Fig. 60, Plate 41, the rear saddle were omitted and the shape of the frame were disregarded, a fair representation would be obtained of the Berkshire in respect of the relative positions of the points of bearing, the saddle, the treadles, the driving wheels, and the steering

wheel in front, which was steered like that of a bicycle by means of handles placed in front of the saddle. The treadles were mounted in the centre, immediately underneath the saddle, so as to admit of the rider's utilising his weight to the greatest advantage in driving. There were also two separate driving chains, to provide for two speeds; and a powerful brake, which, when applied, remained in constant action until purposely released. In that tricycle therefore, he submitted, the correct distribution of wheel load was carried out in such a manner that the rider's safety was provided for, and the greatest facility was given him for utilising his strength in the most profitable way. Corroboration of these views was afforded by the large number of tricycles already in use, in which the leading features of the Berkshire were retained. The questions of general appearance, weight of machine, and rate of propulsion, he considered were of secondary importance in comparison with the provision made for the rider's safety.

Mr. F. G. M. Stoney believed he had himself been one of the first who had ridden about on wire wheels, having twenty-three years ago made for himself in 1863 a four-wheeled velocipede, of which he now exhibited a photograph. It had two rear-driving wheels of 5 feet diameter, and two leading wheels of 4 feet diameter; and the spokes were of No. 17 steel wire or 0·06 inch diameter. Some time afterwards it was bought by a gentleman, with whom it ran away down hill, and he believed it had never been heard of since.

As to the name "dicycle" for the Otto bicycle, he would suggest "twin cycle" as much more appropriate. It was a monocycle divided or duplicated, and therefore might properly be called a twin cycle.

A great desideratum for all tricycles was a compound driver, or a method of transmitting power to both wheels from the central gear or from the side gear by means of a positive driver of such a kind that neither wheel could go back upon the axle; either wheel might over-run the axle, but neither could under-run it. The ordinary balance-gear, which was used in traction engines and by Messrs. Starley in tricycles, could not be called a positive driver, because it was positive only so long as the resistance upon the two wheels was

(Mr. F. G. M. Stoney.)

equal. If one wheel encountered more resistance than the other, that wheel went slower than the axle, and the other was then compelled by the balance-gear to go faster than the axle; consequently there was a tendency for the tricycle to swerve round towards the side on which the greater resistance was met with. In Figs. 78 and 79, Plate 46, was shown a positive clutch-gear that he had produced, which would drive in both directions, forwards and backwards, and was of very simple construction. Each of the two tubes forming the driving axle AA had a small ratchet-wheel R keyed upon it; and upon the boss on the outer face of each ratchet-wheel was mounted a loose annular disc D. Between the pair of ratchet-wheels was the chain-wheel C, which was mounted loose upon the axle, and had its rim spread out wide enough to cover the discs D on each side. The chain-wheel was made with five arms, of the shape shown; and through the spaces between the arms passed five bolts or pins, by which the pair of annular discs DD were strongly bolted together. Each bolt formed the centre pin for four pauls P, which were arranged in two pairs for engaging with the pair of ratchet-wheels R. Supposing the chain-wheel were driving forwards in the direction of the arrow in Fig. 78, it was seen that in the topmost pair of pauls the forward paul was fully engaged in the ratchet-wheel and was driving it forwards, being held in gear by the thrust of the small helical spring compressed between the forward and the backward paul of each pair. The backward paul, receiving the driving pressure from the arm of the chain-wheel bearing against it, was kept out of gear, and could not by any possibility become engaged with the ratchet-wheel so long as the driving pressure of the chain-wheel continued to be in the same forward direction. The line of the driving pressure from the chain-wheel, passing through the centre-pin of the paul, was at right angles to the face of contact of the paul with the tooth of the ratchet-wheel; there was therefore no tendency for the paul to slip out of gear while driving. In going round a curve towards either side, the outer driving-wheel was able to over-run the chain-wheel, because its ratchet-wheel was free to slip forwards under the driving paul, though prevented by the paul from slipping backwards or under-running. On reversing the direction of the chain-wheel for

driving backwards, a slight backward motion of the loose chain-wheel through only one or two degrees of the circle was sufficient to raise the forward paul out of gear and to throw the backward paul into gear; and it would be seen that the forward paul was safely lifted clear out of gear, before the backward paul could engage with the ratchet-wheel. Hence on reversing the pedal action the one set of pauls was disengaged and held out of gear, while the reverse set immediately came into gear; and thus a double-driving clutch was obtained, which was instantaneous for driving in both directions, and was positive in its action instead of being differential. In order to get a sufficiently strong ratchet-wheel of small diameter, it was made of coarse pitch, having only thirty-six teeth for the five sets of pauls to gear into; and as thirty-six was not a multiple of five, the result was a sort of vernier, whereby the thirty-six teeth of the ratchet-wheel were rendered virtually equivalent to 180 subdivisions of the circle. Hence the chain-wheel could not run loose through more than two degrees in either direction before one or other of the five sets of pauls would come into gear with the ratchet-wheels. In going round a curve, the driving was done by the wheel on the inner side; this he maintained to be the right plan for a positive driving action, which could not be obtained otherwise; and the outer wheel had then to over-run the driving. Supposing it so happened that, on resuming a straight line after the curve, not one of the five pauls belonging to the outer wheel was in gear at the moment, the utmost extent to which the outer wheel could lag or slip was only 1-180th part of its circumference before the nearest paul would be brought into gear; and such a driving action he thought was instantaneous and perfect enough for all practical purposes.

From many years' experience of carrying heavy loads upon free rollers, in work not at all connected with tricycles, he had been much surprised in some instances at what he had seen of the ball-bearings used in cycles, in regard to which he believed there was a general misapprehension as to what their advantage was. Friction itself he considered was the smallest element of resistance in a cycle. The machine was constructed with a very delicate frame, and therefore could not have bearings of any length—no

(Mr. F. G. M. Stoney.)
matter how beautifully made—because locking would take place; and it was the locking in bearings that caused the resistance, not their friction. Cone bearings had been tried, and had been found to be very bad; because the better they were adjusted, the more did they aggravate the tendency to locking. The advantage attending ball-bearings was not that they had a beautiful rolling motion, because they had not; in most cases the action was that of grinding, and in many of the bearings which he had seen it was a matter of mathematical impossibility that the balls should roll freely; they did not roll. The real advantage in a ball-bearing was that the bearing was narrowed down from a journal to a mere line; and therefore, however the frame might twist, it could not lock the bearing. Not only was the bearing reduced to a single line, but even in that line no more than a single ball was bearing at any one time; even if any of the others might happen to be bearing a very trifling amount, yet it was the uppermost ball which really carried the load for the time being; and it was because it was a ball, and not a fine-edged disc, that the bearing point was kept renewed and there was an entire absence of locking. The diagram sketched in Fig. 80, Plate 46, illustrated his own view that a ball-bearing should be treated exactly like a conical bearing or a pair of mitre wheels or bevil wheels. This was a point which he believed was generally neglected; for all the ball-bearings which he had examined had got a curve at each side of the ball, and it was that curve which appeared to him objectionable, because he did not believe in the possibility of getting any curve in exactly the right place for keeping the ball rolling in the same way that it would do in a proper conical bearing. For simplicity therefore he considered it would be preferable that the outer portion of the bearing should be shaped at right angles, as shown at B and D in Fig. 80, because that was the simplest possible form. Then a line drawn through the two points of contact at B and D would be at an inclination of 45 degrees to the axis of the bearing, and its intersection with the axis at A would be the apex for the cone, from which a tangent drawn to touch the opposite side of the ball at C would itself give the proper cone for the surface of the conical journal. As the circular paths described by the ball's three

points of contact were not of equal diameter, the rolling motion of the ball would be of a differential nature. It would be seen that this simple construction of ball-bearing had the advantage that the three bearing surfaces could all be made perfectly true and with the utmost ease.

Mr. Arnold Goodwin, Jun., mentioned that he had had experience both with ball bearings and with roller bearings for cycles; and in a cycle he had been riding, which was fitted with ball bearings, he had found that the load was so concentrated upon the journals that ultimately the axles broke across at that part. By substituting long parallel bearings, three or four diameters long, he found that the machine, which was one of the ordinary make, ran more easily on a level asphalt road than when it had ball bearings; and he had never since had any trouble with the axles breaking. If the ball bearings had really proved a great success, he should have expected something would be heard about them in connection with railway vehicles. At the present time he knew endeavours were being made to adapt the ball bearings for railway carriages; but he thought the same result would be experienced that he had already found with the axle of the cycle.

Mr. Arthur Paget recalled the fact that ball bearings had been first introduced for the forks of bicycles, and had there proved to be a great success, because the fork of the bicycle was exposed to great cross twists, which rendered it impossible for an ordinary bearing to work satisfactorily. When ball bearings were applied, they obviated the friction caused by these cross twists; and if instead of ball bearings the axle were to have semi-circular grooves turned in it, and semi-circular ring-bearings in the grooves, the friction caused by the cross twists would by that means also be obviated, and nearly as good an effect would be obtained as with ball bearings. Though admirable in the fork of a bicycle, the ball bearings when transferred to the main axle of a tricycle were an unnecessary complication.

(Mr. Arthur Paget.)

In regard to the statement that the road resistance to a wheel varied inversely as the square root of the wheel's diameter, under the same load, whatever the roughness of the road, it appeared to him that there must be a serious error. For if a small wheel encountered an obstruction so high as to reach up to its centre—say a 10-inch wheel meeting a rut 5 inches deep—it was clear that the wheel would be incapable of surmounting it at all, whilst a wheel of larger diameter would be able to do so easily; and it therefore appeared that the proportions of the road resistance as between any two wheels of diameters differing considerably must vary very materially according to the varying roughness of the road: so that a rule such as had been given, while correct for one road, must be wrong for a road the roughness of which was greater or less.

Mr. W. T. SHAW explained that the relation which he had expressed between rolling resistance and wheel diameter held good only within reasonable limits. The criticism just offered was carried beyond those limits, because when an obstruction was raised to the same height as the axle, it became a dead obstruction in front, and there was no longer any question at all about rolling resistance.

Mr. GRIFFITHS said that, although the subject of the paper was not the propulsion and guiding of cycles or the construction of their bearings, but the distribution of the wheel load, he should nevertheless be happy to reply to the remarks which had been made upon matters of interest that were not strictly germane to the paper.

With regard to the name "dicycle," for the convenience of the railways all velocipedes were classified either as tricycles or as bicycles, or as bicycles in which the two wheels were placed side by side; but the last designation was so lengthy that he thought it would be a great simplification to say merely tricycles, bicycles, and dicycles. "Twin cycle" would of course do as well as dicycle, were it not that a single word derived wholly from one language seemed preferable to two words from different languages.

In regard to including the Humber and the Meteor both under class A, Mr. Boys was quite right that there was a very important difference between these two tricycles; but as their wheel-base was really the same, they had been classed together in the paper, in order to avoid making too many classes. Practically the Meteor, in which one only of the two front wheels was the driver, had now died out; and there remained only the Humber, and one or two other tricycles which seemed to be now coming up again, though not yet very prominently, in which the central hind wheel was the driver. The latter kind of machine he thought had a great future before it.

The amplifications made by Mr. Boys as to the variation of the wheel load from dynamical considerations were quite right; but they really referred more to the question of propulsion and guiding than to that of wheel load. His remarks about the variation of the wheel load by the action of the rider upon the pedals and driving gear, and about the action of the brake in front-driving and rear-driving cycles, were also apt, and added to the force of the arguments in the paper.

A little modification was required in page 140 of the paper, where it was said that, when only one of the two front wheels was a driver, the weight on the rear steering wheel was so greatly reduced by the effort to drive at a high speed. That reduction was not a consequence of the reaction dwelt upon by Mr. Boys, which would certainly tend to increase the weight upon the hind wheel; but it resulted from the fact that every rider when going at a high speed leaned more forwards. In the tricycles of class A, particularly those of the older patterns, the rider's weight when he leaned forwards was very often wholly upon the front axle; and consequently the back wheel, being entirely relieved of load, instantly tipped up and lost its steering power. It was more this action which he had had in mind in that part of the paper than the reaction consequent upon the driving force exerted by the rider.

With regard to the assumption on page 154 of the paper, that two-thirds of the rider's weight in driving was transferred to the pedal axle, of course that was only a very broad assumption. Obviously it would vary with every different make of cycle, and

(Mr. Griffiths.)

more particularly with every different habit of rider. Still in order to get anything like a uniform comparison of the various cycles, it was necessary to make some such assumption, and he believed it was a very fair average for the purpose.

The illustration furnished by Mr. Boys of the gyroscopic stability of cycles was very apt. As to the positive driving of the Otto dicycle, that problem was well known to be a most intricate one: which was the reason why it had not been accomplished. The integrating machines referred to in Mr. Boys' remarks were of so very elaborate a nature that he could not say they would always be suitable for the rough usage to which cycles were subjected.

With regard to the management of the Otto dicycle, Mr. Boys had mentioned that it took him about a week to learn to ride it; whereas Mr. Marsland's experience with the Spinaway tricycle showed that this did not require a week for learning it. For without having previously seen anything whatever of the Spinaway tricycle, or having had any previous riding on other cycles, he got on it at once and was out for a whole morning, and was very often in advance of other riders who were going along the same roads. This instance well illustrated the ease with which the Spinaway put an inexperienced rider into a good position for riding; and clearly showed that it retained the advantages both of the Otto and also of the tricycle, combining these with safety and ease of learning.

In reference to the size of the wheels, the statement that the road resistance varied inversely as the square root of the wheel diameter was one which he did not recollect having met with previously. At any rate, if correct, it added to the general force of the argument in the paper; for a 4-ft. wheel would have to encounter only half the resistance of a wheel of 1 foot diameter, and a 9-ft. wheel one-third. Consequently a very big wheel did not gain anything like in proportion to its diameter; and therefore, as urged in the paper, it was desirable to keep the wheels down to a moderate size, without having them too small.

The idea expressed by Mr. Soper, that the centre of gravity of the rider was so high above the saddle as the centre of his body, appeared to him to be rather mistaken. If the rider were to sit upon

the saddle and just simply balance himself with his legs raised in the air, he would find that his centre of gravity would be no more than a few inches above the saddle, not so high as the centre of his body. In the paper the rider's centre of gravity had been taken to be at the saddle, because his legs were generally well below, and they formed a large portion of his weight. The centre of gravity of the rider he thought was not more than two or three inches above the saddle at most; and that of the rider and the machine together would very often be below the saddle.

As to putting the base of the triangle of stability at the centres of the wheels, instead of at their points of contact with the ground, certainly so long as the wheels were running freely the comparison thereby arrived at would be a very similar one to that drawn in the paper; and possibly the graphic estimation so afforded of the stability of the various outlines would be equally accurate. But when the brake was powerfully applied, so as almost to skid the wheels, then he thought the fulcrum or point of stability was really transferred to the ground. The Berkshire tricycle had certainly anticipated many of the recent developments which had been so very largely advanced during the last winter; the only misfortune seemed to be that it had been several years before the time, and he trusted therefore that it would now have better success.

The double clutch-driver described by Mr. Stoney was well known in principle to all cycle manufacturers. The disadvantage attending all clutch-drivers was that in going round a curve it was the inner wheel which did the driving; they were rather noisy, in consequence of the outer wheel having to over-run its own ratchet or clutch. Balance-driving, either with the Fowler gear or with any other of the train-arm gears, presented precisely the same efficiency, while free from the noise of over-running. It had also been stated that tricycles driven by balance-gear were liable to swerve. His own experience was that at a very low velocity—taking the Spinaway tricycle for example, and lifting the little pilot wheel entirely off the ground, and riding like the Otto—the application of the brake to either wheel would then cause the machine to swerve; but if it were going at four or five miles an hour the gyroscopic stability would

(Mr. Griffiths.)

keep it almost straight even in running over a brick. Running at a fair velocity he had found there was no difficulty from the independence of the two wheels with the balance driving-gear.

As to ball bearings, the principles laid down by Mr. Stoney were adopted, he believed, in all the best cycles. In the Spinaway tricycle the main bearings were constructed exactly on those principles, with only the slight variation that instead of a perfectly straight cone the outline of the surface was a flat curve. One reason for this was that in wear the balls gradually buried themselves into the surface of a straight cone; and therefore, when the surface was made slightly hollow to begin with, the variation of the outline was less after a certain amount of wear than if the surface had been a true cone in the first instance. In the discussion which followed Mr. Phillips' paper at Coventry (Proceedings 1885 page 510) it would be remembered that Mr. Boys' remarks as to the wearing of the balls showed that the amount of their wear was infinitesimal; but he thought that, instead of examining the balls only, the cases in which the balls ran should also be examined, for he had found that it was the cases that wore, and not the balls. In examining the bearings made by all the best makers, he had invariably found that, after a certain amount of running, the cases had grooves worn in them by the balls; the balls themselves might show hardly any signs of wear, even when the cases were made thoroughly hard. This he took to be the reason why the makers put a little curve into the cone, instead of making it a straight cone; because when it was curved the deviation by wear was found to be less than if it were made a straight cone in the first instance.

The swivelling of the bearings, referred to by Mr. Paget, was of course a most important point. Having himself used in tricycles long bearings, two or three diameters long, fitted with universally swivelling connections to the frame, he had found they worked very nicely; but one difficulty was that they took up a great deal of room on the machine, and they also required a great deal of oil. The great advantage of the ball-bearing was that it could be run for a hundred miles with only one oiling; and the quantity of oil put in was very much less than was needed to run a long parallel journal

for ten miles. These conveniences were quite sufficient he thought to establish the advantage of ball-bearings over plain journals. Moreover a long plain journal must have some sort of universal swivelling joint, whatever it might be, for enabling it to follow the twisting of the machine or the elasticity of the frame itself. Universal swivelling joints were also desirable for some of the ball-bearings, which were just as capable of jamming from twist as long parallel bearings. The same consideration applied also to Mr. Goodwin's remarks as to the use of ball-bearings or roller-bearings in railway carriages. In that case it was a question as to the size and number of the balls that would be required; because it was a very different thing to carry a 10 or 12-ton railway carriage on its axles, and a tricycle of which the weight with the rider was only 300 lbs. To carry such a tricycle only 30 balls were required, or about 10 lbs. per ball; but the number of balls that would be required to carry out the same principle for the 12-ton railway carriage would be found to be very considerable and most probably inconvenient in arrangement.

The PRESIDENT believed this Institution was the first which had seriously taken up the consideration of cycles of various kinds as most important pieces of mechanism. It was said that familiarity breeds contempt; and both bicycles and tricycles were now everywhere so plentiful that they were sometimes voted a nuisance, and thought unworthy of recognition by dignified engineers. But he was sure that those who had heard the present paper, and the one lately read, and especially those who had enjoyed the advantage of going over the makers' works at Coventry, must have felt that these machines were very well worthy of the attention of mechanical engineers, and that cycles had come to be a most important feature in modern civilisation. Of course there were two ways of riding a cycle, as there were of riding a horse. A beginner usually looked most awkward, and soon exhausted himself; but a skilled cyclist rode almost vertically, and was careful to adjust the height and position of his seat, so that he could go along quietly and steadily, and not waste any of his strength. The sphere had been spoken of

(The President.)

in the paper as the simplest and perhaps the earliest kind of monocycle, but too difficult to ride except for acrobats. Perhaps the oldest monocycle, and the most important, was the earth itself; and it was the only one on which there were more than two riders, and yet none of them had a tendency to fall off.

With regard to cycling generally, good roads were essential if there was to be any pleasure in it. It was no use trying to cycle much in winter when there were stones on the roads, or against strong head winds or in wet weather; there was no pleasure and no advantage in it then. But under favourable circumstances—namely in fine weather, on good hard roads, and in the absence of wind—it was one of the most exhilarating recreations that anyone could possibly enjoy. A series of articles had been written by Dr. Richardson in the Fortnightly Review some time ago, which would incite almost anyone to take a delight in this pastime. The time he also thought had almost come when special cycle ways might be made with advantage between populous centres, as between London and Brighton. Numbers of persons, to whom the expense of railway travelling was a consideration, might ride with the greatest ease to and from Brighton along such cycle ways, and in such numbers as to make it worth while to lay them down.

The ordinary bicycle, notwithstanding that he admired it very much and considered it was a most marvellous contrivance, had always seemed to him to be at the best a dangerous vehicle. A comparatively slight inclination downhill, or a slight obstruction in its way, or even a little ridge or hollow in the road encountered on a dark night—any of these causes might occasion an accident; and when an accident did occur, the rider was thrown over on to his head. Many persons had lost their lives, and many more had sustained serious injuries. He was therefore very glad to see the development of such machines as safety bicycles and tricycles. Although these might not perhaps be so elegant to look at, there was no doubt that a machine like the one now exhibited was practically safe. In fact he had seen a rider on one of them go over an obstruction equal to two bricks, one placed on the top of the other, as easily as possible and without any danger or difficulty whatever.

He had long had a notion that more consideration should be given to the adaptation of the gauge of the tracks in tricycles to the best parts of ordinary roads. With a bicycle there was only one track to think of; a rider could thread his way along the best part of the road, and avoid all visible obstructions. On ordinary roads there were generally two good tracks, namely the two which were made by cart or carriage wheels, and which were just 4 feet 8½ inches apart. In between these and outside of them, the road was liable to be more or less loose and stony. If therefore tricycles could be so constructed that they should have two tracks only, and that these should be just 4 feet 8½ inches apart, they would thereby be enabled to remain always upon the best part of the road. But in the present tricycles, of the class in which the apex of the wheel triangle was forwards, one wheel might run in a good track, but the other two were more or less always on bad ground, the width of the machine being much less than 4 feet 8½ inches. In the Spinaway indeed one of the driving wheels and the pilot wheel were practically both running in one track, but the other driving wheel was always liable to be in a bad part of the road. For carrying two people, the tendency latterly had been to avoid the sociable, in which the riders sat side by side, and to put them fore and aft as in the tandem, and in that way the machine was kept as narrow as a single tricycle; but there was then always the difficulty that only one of the wheels, or only the wheels on one side, were in a good part of the road. Now in riding with a companion it always seemed more pleasant to have him by your side, as in a carriage or gig, than either behind or in front. Why therefore should not a sociable be made with the wheel gauge the same as that of a gig, namely 4 feet 8½ inches? Such a tricycle would have only two tracks, and its wheels would always be running upon the best parts of the road. There was no reason why there should not be two steering wheels in front, one in front of the driving wheel on one side, and the other in front of the opposite driving wheel. His idea might be somewhat crude, but he had not heard it suggested either in the paper or in the discussion; and looking at the increasing number of cycles for two riders, he thought it would be desirable to recognise the existence of the two tracks in

(The President.)

every road, 4 feet 8½ inches apart, and to make all the wheels go into one or both of those tracks.

He now asked the members to pass a hearty vote of thanks to Mr. Griffiths for the able and instructive paper which he had contributed.

ON THE RAISING OF THE WRECKED STEAMSHIP "PEER OF THE REALM."

By Mr. THOMAS W. WAILES, of Cardiff.

This vessel, a screw steamer of 1813 tons net register and about 300 feet length over all, laden with 2600 tons of coal, ran on the rocks on the east side of Lundy Island during a fog on the 11th of February 1885. Her position was a dangerous one, as shown in Fig. 5, Plate 49, being within 30 feet of perpendicular cliffs more than 200 feet high, where it was impossible to land; the only landing place on this little island is at the south-east corner, and is approachable only in fine weather. After careful examination of the wreck, although she had been given up as a total loss, the writer was confident, from his experience in the successful raising of several previous wrecks, that she could be profitably raised; and on the 13th of July he was commissioned to undertake the operation, which was carried out according to the following plan.

The after part of the vessel being double-bottomed throughout its length of 80 feet, as shown in the longitudinal section of the vessel in Fig. 1, Plate 47, the water neither rose nor fell so fast inside as the tide outside. In this part it was considered that the leakage could be kept under by two 8-inch centrifugal pumps PP, after throwing overboard a large quantity of coal so as to lighten the vessel and to form a well from which the windbore of the pumps could draw, as shown in Figs. 1 and 2, Plate 47, and in Fig. 7, Plate 50.

Amidships it was decided to do nothing beyond securing as firmly as possible the bulkheads fore and aft of the space occupied by the engines, boilers, and coal bunkers; and to allow the water in this space to rise to its level.

Throughout the 142 feet length of the fore part of the vessel, from the boiler-room bulkhead HH to the stem, it was decided that the coal stowed in the hull must be platformed over, as shown in Fig. 1, Plate 48, and in the cross section, Fig. 3, Plate 49, with a timber deck strong enough to serve as a new bottom and to keep the wreck afloat with the assistance of two 8-inch centrifugal pumps PP.

For carrying out these operations, the steamer Hoy Head was chartered, and on board her were placed four 8-inch centrifugal pumps, with engines and boilers for working them; also the whole of the timber for platforming the fore part of the wreck, and a large quantity of other materials and appliances. Everything was so arranged that what was first wanted was uppermost, and was easily got out by the aid of the steam winches. The Hoy Head was also fitted with the requisite accommodation for the workmen, fresh-water tanks, cooking appliances, &c.; she thus served during the whole of the time both as workshop and home for all the men employed on the work.

The tides had to be carefully considered, and every advantage taken of them when at their lowest, inasmuch as very little could be done during neap tides. At the lowest tides there was 12 feet of the wreck under water at the stem, and 21 feet at the stern, as shown in Fig. 5, Plate 49, and also by the sloping water-line in Fig. 1, Plates 47 and 48; but only for a short time, as the tide falls and rises very rapidly. At high water her masts only were to be seen, the highest high-water line being about 29 feet above the lowest low-water line, as shown by the dotted line in Fig. 5. As soon as the rising tide drove the men from the wreck, they occupied themselves on board the Hoy Head in preparing the materials for the next ebb. Whenever easterly winds prevailed, these prevented any work from being done upon the wreck; and on some occasions the Hoy Head had to go for refuge to Ilfracombe.

Operations at the wreck were commenced on the 24th of July 1885 and continued until the 30th, when they had to be suspended on account of bad tides. Work was resumed on the 5th of August, and by the 12th the platforming was completed on the top of the lower

stringers in the fore part. With the aid of the steam winches a large quantity of the coal was thrown overboard from the aft part, as shown in Fig. 1, Plate 47, and some also from the fore part, when the tide was down; and all heavy weights to be placed in the wreck were deposited in almost exactly their intended positions, where they were then quickly made secure.

The platform beams of spruce pine 10 inches square were laid transversely on the top of the coals in the fore part of the hull, being placed 4 feet apart, as shown in Figs. 1 and 3, Plates 48 and 49. Each was in two halves with a long scarf joint well bolted together; the advantage of this plan was that they were easily handled and got in between the iron stanchions, and fixed in their places more expeditiously. From dimensions taken at low tide the several pairs of halves were prepared beforehand on board the Hoy Head away from the wreck while the tide was up, during which time the men were kept fully employed in getting ready the materials for the next ebb. The platform or deck was made of longitudinal planks LL of spruce pine, Fig. 4, Plate 49, 11 inches wide by 3 inches thick, nailed down upon the beams, and further held down by a transverse plank T of the same size laid over them at each beam. Upon this plank were footed the upright timber shores SS, Fig. 3, some of them 10 × 5 inches and the rest 11 × 3 inches, each firmly fastened at bottom between two chocks of wood nailed to the plank T and to the shore; the upper ends of the shores were securely tongued to the ship's iron beams. About 2 feet above the centre of the upright shores, a connecting batten N, 3 × $1\frac{1}{2}$ inch, ran across the ship, securing all the shores to one another in each athwartship row. The spaces between the iron frames at each side of the ship—most difficult places to make watertight—were each filled with a wooden chock, well driven in and caulked; and an upright shore was fixed on each of these chocks, with its top end bearing under the deck above, as shown in Fig. 3, so as to prevent the slightest upward movement of the chock. Over the chocks and round the frames was laid a body of best Portland cement, 3 inches thick, as shown black at CC, Fig. 3, and shown also in the plan, Fig. 4, which set hard

and made a most complete watertight job. In way of the hatches were placed additional transverse beams E, as shown in Figs. 1 to 3, for taking the upward pressure of the shores in these places. As the platform had to be fixed so low down in the wreck, there was very little time in each tide for carrying out such a large undertaking; nevertheless the work was successfully and speedily accomplished, principally through the efficiency of the arrangements adopted as above described, and without the aid of divers for any part of the operations.

After the platform had been caulked and finished, the two iron pump-wells W were fitted in it, one in each of the two compartments into which the fore part of the ship was divided by the iron bulkhead A, Fig. 1, Plate 48; and a hole was cut through the bulkhead for allowing each well to get an equal share of water. When all the work had been tested, two 8-inch centrifugal pumps PP were placed on the main deck, one to draw from each well. So complete was the workmanship found to be, that the pumps were not required to work more than half their time during the tedious voyage of sixteen hours from Lundy Island to Cardiff.

On the morning of the 14th of August it was determined to make the attempt to raise the wreck. With the receding tide steam was got up in the four deck boilers B, Figs. 1 and 2, Plates 47 and 48. Before break of day the wreck was felt to move slightly with the rising tide, and at 5·45 A.M. she was completely afloat. After another careful examination all round, the tugboats received the signal to tow, and in two minutes she was afloat in deep water, towed by four powerful screw tugs, as well as by the steamer Hoy Head made fast alongside her, as shown in Figs. 8 and 9, Plate 51. A speed of seven knots per hour was maintained until abreast of Ilfracombe, and then a slower rate up channel to Cardiff, which was safely reached at 10 P.M. All on deck being a complete wreck, with the bulwarks all swept away, the freeboard amidships was only 21 inches in coming up channel. The displacement with this amount of freeboard was 4780 tons, being the weight of the vessel herself and all she contained; and the displacement up to the

deck being 5180 tons, there was therefore a surplus buoyancy of no more than 400 tons, forming a remarkably small margin for bringing the wreck safely up channel.

After discharging in the following week the remainder of the coal in the after hold only, the wreck was safely docked in one of the dry docks of the Mountstuart Shipbuilding Graving Docks and Engineering Co. in Cardiff. The hull had become coated with large quantities of barnacles and sea-weed; and these having been cleaned off, it was found that her keel, bottom shell-plates, frames, and floorplates were broken in a great number of places for about half her length, affording full scope for the water to flow in and out freely, and thus proving the platforming to be the best method that could have been adopted. On carefully examining the hull after being docked, it was very gratifying to find that, although the wreck had been exposed to much severe weather, she had not strained a single butt or rivet in her topsides, the whole of the damage to the hull being below the bilges. Her rudder and sternpost being broken and useless, she had to be steered by manipulating the tugs towing her up to Cardiff. As shown in Plate 47, the heavy seas rolling over her had completely smashed in the after deck, as also the bridge, and the engine and boiler casings, &c.

In addition to the execution of the necessary repairs, all of which were carried out in conformity with the requirements and under the supervision of Lloyd's and the Board of Trade, the steamer was thoroughly overhauled and remodelled internally. Having been completed as shown in Fig. 10, Plate 51, under her new name of the "Dunbar" she left the graving dock on the 11th of January 1886 for her trial trip in the channel, which went off without a hitch, and was in every way satisfactory.

Discussion.

The PRESIDENT asked the author if he could add anything in regard to some of the contingent difficulties that could not be foreseen, which must no doubt have been met with in an operation such as was described in the paper, particularly at the moment of getting the wreck afloat in deep water.

Mr. WAILES said that in all operations of this kind, for the lifting of vessels, there was a great deal of risk to be run: in fact the moment that was thought most secure, when everything was believed to be safe, frequently turned out to be the fatal moment, as it nearly did on this occasion. On the morning when the vessel was lifted, the sea was perfectly calm, with scarcely a ripple on the water; but away to the north-eastward of Lundy Island was a race called the White Mare, where there were very considerable waves through the meeting of two tides. The pilot in charge of the wreck ought to have kept clear of that race; but instead of doing so he took the wreck right into it, and before they knew where they were the vessel was heaving, and the next minute the seas came rolling over the deck, carrying overboard the coals that were on deck and everything else that was lying about, and sending the men up from below. The pilot instantly left the wreck, and went on board the Hoy Head. The next thing was that the two pumps on the after end stopped pumping, in consequence of the coals falling on the top of their nozzles. All the men naturally left the vessel there and then, with the exception only of his foreman and himself, who stood by and tried to get the others to come back; but they would not for some time. At last however the tugs got the vessel through the race, and she was in still water again. Then the men came back to her, and got down into the after end and disconnected the after suction pipes: they took out the lift, and then got the pumps started again, but not before the ship was within 5 inches of foundering. The original 21 inches of freeboard, with which the wreck had been got afloat, had been reduced to only 5 inches, in consequence of the water

accumulating so fast through leakage and through the seas breaking over the deck. As a provision against anything of this kind taking place, the after tug boat, called the Levant, had been engaged, having been specially built for salvage work; she was fitted with a large centrifugal pump of 15 inches diameter, which was worked by her main engine, having three 8-inch suctions and one 15-inch delivery, capable of discharging about 1000 tons of water per hour, and was furnished with coupling hose for connecting with suction pipes fitted into the after part of the wreck. When in the race he hailed that boat to come alongside, but she could not do so: she would have been knocked to pieces, inasmuch as the 12-inch beams between the wreck and the Hoy Head were all knocked to matchwood through the collision between the two vessels in the race. As soon as they got into somewhat smooth water the Levant came alongside, and connected the large flexible suction-hose and started pumping at once; and with the aid of the other pumps the water was pumped out in about five minutes through a depth of about 4 feet. Previously to getting into the race, the water had been down nearly to the nozzles of the suction pipes, before the fall of the coal against them.

In operations of that kind it was necessary to look ahead, and to endeavour to be ready for all sorts of emergencies, such as might arise in ship lifting. The first mishap which had occurred, and had seemed likely to stop them from getting away at that tide, had been that one of the after pumps would not work; it stopped suddenly, the slide-rod got disconnected from the slide, and there was a jam. It was thought that the pump had choked; but eventually it was found that some of the nuts had got loose. These were soon put right, and the pump got to work; but it was a serious moment, because on account of the tide the wreck when afloat could not be held in position for want of some shore connections. If she had gone down in deep water, she would have been lost altogether, as it was a rock-bound coast where there was no beach on which to run her aground. Fortunately he had succeeded in getting the pump to work in time, and then in getting out of the race, and in bringing the ship to Cardiff in safety.

Mr. DRUITT HALPIN considered this had been an exceedingly difficult work, creditably carried out. Only those who had had to do with such operations could realise what the difficulties were. The whole work had been done in a remarkably short time, and the arrangements must have been well planned beforehand. One point that he admired very much was the great care that had been taken in regard to the commissariat, which was certainly the first thing to look after in all such jobs, in order to keep the men together on the spot so that no time should be wasted: work being also provided for them whenever possible during the times when they could not be actually employed upon the wreck itself. The bulkheading and platforming for the purpose of getting flotation had evidently been very efficiently carried out, as the result had proved. Such jobs were exceedingly awkward and precarious to tackle; he had had one job of the kind himself, and had experienced very much less luck. In that instance the ship, having suddenly been caught in a fog, lost her way, and ran upon a stone wall on the top of the tide: when the tide left her she hogged, and one-third broke off like a candle, and fell away from her altogether. Before he took charge of her, the end broken off, which was 120 or 130 feet long, had been bulkheaded up; and that end was taken away and saved, and was eventually cut up for old materials. The other part, about two-thirds of her whole length, was lying at an angle of about 30°, down in the water, and was only partly uncovered at low water. He had the assistance of a steamer and barge, so that all the men lived there; and they worked very hard at her day and night for three weeks, and got the bulkheads in and the pumps and everything ready for lifting her at the next tide; but a gale came on, and broke her back in the middle, and she went down in deep water, and nothing more was to be done. When therefore such very precarious jobs were successfully carried out, great credit was due to those who undertook and accomplished the work.

Mr. JOSEPH TOMLINSON, having spent about fifteen years of his life in Cardiff, had seen a great many difficulties connected with the lifting of vessels; but he did not remember ever seeing an instance

in which the difficulties of such a work had been more successfully battled with than on this occasion. He should like to know something about the cost of the operation—both of lifting the ship and of repairing her—in order to see what the real gain had been. Knowing the place very well where the vessel was wrecked, he could fully appreciate the difficulties of raising her, and was very much pleased with the manner in which the operation had been so successfully carried out.

Mr. W. A. Gorman believed this was the only maritime nation of any importance which was without a properly organised salvage association for raising wrecks. Although the mode of operation adopted by the author was not a new idea, he was to be congratulated on the success with which it had been carried out. The difficulty had not been so very great as it would have been if the work had had to be done with the aid of divers; but if there had been a diver on board at the time when the after suction pipes became choked, he thought the delay in disconnecting the pipes would have been saved, and the pumps would have been got to work again more speedily. In that one particular it seemed to him there had been a slight oversight; in other respects the work appeared to have been properly carried out, with the exception only of the cement, which he imagined, if there had been a heavy sea on, might have been liable to be lifted, in consequence of not being protected on the top.

Mr. W. B. Caulfield said the operation described in the paper, which had been so successfully accomplished, was one that was always attended with considerable difficulty, and in many cases would be totally impossible. For instance, where the vessel was submerged, the platform could not be constructed. It was only in cases where the tide left the vessel partly uncovered, and the workmen could get in low enough, that the platform could be constructed. For the last twenty-five years the plan of putting a platform in had been more or less used, especially in the northern ports of the kingdom. In Glasgow there was a regular organisation of workmen with all necessary appliances, and the whole of their

(Mr. W. B. Caulfield.)

operations were based upon the plan of platforming, so that the men became quite expert. In laying the platforms they never used cement, but always had the joints thoroughly fitted at the ship's side, by one piece of longitudinal timber with all the recesses cut in it so accurately that it required very little caulking indeed, and could never be displaced. In the case of the wreck described in the paper, there was a body of coals underneath the platform, which had probably made the platform more stable, and less liable to be disturbed by the sea rising suddenly and washing against the underside of the platform and shifting it in any way; the coals would have a tendency to prevent that, and no doubt did so. Otherwise it was very probable that more leakage would have taken place than the pumps here employed would have had power to contend with. With reference to the size of the pumps, in a case of such magnitude and so dependent on the pumping power as this, he thought that 8-inch pumps would be found practically not so good as 12-inch pumps. One 12-inch pump would be quite equal to two 8-inch pumps: it would be much more easily worked, fewer hands would be required, and it would not be so liable to get out of control. In one case in which he had been concerned about two years ago as the underwriters' agent in Glasgow, there had been four 12-inch pumps and two 8-inch, all at work together; and it had been found that the 12-inch pumps were quite as handy as the 8-inch, and a great deal more serviceable.

Mr. Wailes said this was the only case in which he had used cement. Two or three years ago he had lifted the steamer Mardy off the rocks at Breaksea below Penarth, by platforming her; and had endeavoured to make the corners perfectly tight by cutting the wood to fit, and shoring it down and caulking it well; but for all that, a leakage would go on at times, which was wanted to be kept down as much as possible. In the present instance therefore he had determined to try cement on the top of the wooden chocks that were fitted between the frames, and it had certainly answered admirably, though with the ample pumping power that was employed the job would have been good enough without it.

The suggestion had been made that it would have been advisable to have a diver in readiness, in case of anything happening to the suction pipes. For fear of anything happening such as did happen, blocks and tackle had been provided all ready over the suction pipes, as shown in Fig. 7, Plate 50, so that if any mishap occurred all that had to be done was to pull the suction pipe to one side and draw it up with the tackle; this they did, and disconnected one length of the pipe, and then dropped the nozzle down again and coupled it up. In that way he had the aid of half-a-dozen men with blocks and tackle, where otherwise he would have had only the diver; and it would have been impossible for the diver alone to free the suction pipes quickly enough. If he had trusted to the diver in this case, instead of to the blocks and tackle which were actually used, he believed the ship would have been lost.

In regard to the size of the pumps, if he had had 12-inch pumps at hand he should no doubt have put them on the wreck; but as they were not there and he had the 8-inch pumps handy and was perfectly sure they would do, he took them; and it was proved that these were sufficient, because one pump in the fore part of the vessel kept her dry in that part, and one pump in the after part was nearly able to keep her dry abaft. The pumps had to be stopped occasionally, just in order to let the water accumulate deep enough for pumping it out. The greatest leakage had occurred above the platform, through which a considerable quantity of water made its way. On each side of the ship there was a cargo door in the bulkheads fore and aft of the engine-room, as shown at DD in Figs. 6 and 7, Plate 50, for allowing the cargo to be taken along; they were iron doors and were thought to be pretty tight; but when the water came against them from the engine-room amidships, the greatest leakage occurred there. More water was made from those doors than from the platform. Being wide they were easily got at; and as he had plenty of time during the day, after getting the wreck safe into smooth water, he had them closed up tighter, so as to diminish the leakage there.

With regard to the cost, the wreck was bought at the auction for £300, including her cargo; the lifting cost about £1,000; and the

(Mr. Wailes.)
repairing and getting the ship away to sea complete cost nearly £10,000, allowing credit for the 1,600 tons of coal taken out after she was got into the dry dock. The total cost did not exceed £11,000, after taking account of all credits. The ship was now insured at the low rate of £12,000; her original cost had been about £33,000.

The PRESIDENT said the author had certainly proved himself a very useful man to his country as well as to himself in saving property of this kind. There were an immense number of vessels wrecked on our coasts, which were never got up at all, and which became total wrecks. At the present time he happened to be upon a committee of a bankrupt estate in the north, where among the assets were four iron steamers which had been wrecked on the coast at different times, and for anything he knew they were there still. An endeavour had been made to sell them; but the only offer that could be got was £10 for the four. If by any such operations as those described in the paper they could be raised and rendered worth £12,000, it was needless to say how gratifying such a result would be to all concerned. It must have been a very anxious moment when there were only 5 inches of freeboard after getting the wreck afloat from Lundy Island. All the difficulties however had been very well got over; and he was sure the members would agree in thanking the author for the paper, in which he had given such an interesting account of the important operations he had so successfully carried out.

ON REFRIGERATING AND ICE-MAKING MACHINERY AND APPLIANCES.

By Mr. T. B. LIGHTFOOT, of London.

The subject of Refrigerating and Ice-making Machinery has not hitherto, so far as the author is aware, been dealt with in a comprehensive manner by any engineering society. The purpose therefore of the present paper is to describe the various systems at present in use, giving also short sketches of their development, together with some considerations respecting their practical application and working: in the hope that this may prove an acceptable contribution to the Proceedings of the Institution, and lead to a profitable discussion upon a subject, the importance of which is daily becoming more manifest.

The primary function of all refrigerating and ice-making apparatus is to abstract heat, the temperature of the refrigerating agent being of necessity below that of the substance to be cooled. It is obvious however that, without provision either for rejection of the heat thus abstracted, or for renewal of the refrigerating agent, equalisation of temperature would ultimately ensue, and the cooling action would cease. In practice, if the machine is to work continuously, one or other of these means must be adopted; and a complete refrigerating machine therefore consists of an apparatus by which heat is abstracted, in combination either with some system for renewing the heat-absorbing agent, or, as is more usually the case, with a contrivance whereby the abstracted heat is rejected, and the agent is restored to a condition in which it can again be employed for cooling purposes.

The subject can be conveniently dealt with under the four following heads:—

1. Apparatus for abstracting heat by the rapid melting of a solid.
2. Machinery and apparatus for abstracting heat by the evaporation of a more or less volatile liquid.
3. Machinery by which a gas is compressed, partially cooled while under compression, and further cooled by subsequent expansion in the performance of work: the cooled gas being afterwards used for abstracting heat.
4. Considerations as to the applications of the various systems.

1. Apparatus for Abstracting Heat by the rapid Melting of a Solid.

This is probably the oldest method of artificial cooling. When a substance changes its physical state, and passes from the solid to the liquid form, the force of cohesion is overcome by the addition of energy in the form of heat. The effect may be produced without change in sensible temperature, if the heat be absorbed at the same rate as it is supplied from without. Thus, as is well known, the temperature of melting ice remains constant at 32° Fahr.; and any increase or decrease in the heat supplied merely hastens or retards the rate of melting, without affecting the temperature. Mixtures of certain salts with water or acids, and of some salts with ice, which form liquids whose freezing points are below the original temperatures of the mixtures, do not however behave in this way; for under ordinary circumstances the tendency to pass into the liquid form is so strong, that heat is absorbed at a greater rate than it can be supplied from without. The store of heat of the melting substances themselves is therefore drawn upon, and the temperature consequently falls until a balance is set up between the rate of melting and the rate at which heat is supplied from outside. This is what takes place with ordinary freezing mixtures. The amount of the depression in temperature appears to depend to some extent on the state of hydration of the salt, and the percentage of it in the mixture. Almost the only salts used are those of certain alkalies, few others

possessing the requisite solubility at low temperatures. A list of freezing mixtures usually employed is given in the appended Table 1, pages 239–240.

Such a method of abstracting heat is extremely convenient for the laboratory, and for some other special purposes. Attempts have also been made to apply it commercially on a large scale for the manufacture of ice and for cooling. The late Sir William Siemens constructed an ice-making apparatus in which calcium chloride was employed. The reduction in temperature produced by dissolving this salt in water is about 30° Fahr.; but as this was not sufficient for freezing when the initial temperature of the water was about 60° or 65° Fahr., a heat interchanger was introduced, by means of which the spent liquor at about 30° was utilised for cooling the water before it was mixed with the salt; and to the extent of this cooling the degree of cold produced was intensified. The salt was recovered by evaporation, and used over again. Although this apparatus worked well and produced ice, the inventor himself considered the process inferior to mechanical methods, and abandoned it.

In the Toselli machine a mixture of ammonium nitrate and water is used, by means of which a reduction in temperature of about 40° Fahr. is obtained. The apparatus consists of a vessel in which the solution of the salt is effected, and an ice-can containing several slightly tapering moulds of circular cross-section and of varying sizes. The moulds being filled with water are introduced into the freezing mixture; and in a few minutes ice is formed round the edges to the thickness of nearly an eighth of an inch. The rings or tubes of ice are then removed and placed one within the other, so forming a small stick of ice.

Ammonium nitrate is also employed in a machine recently brought out in the United States for the production of ice on a large scale. In one form of this apparatus, intended chiefly for domestic purposes, a series of annular vessels, one within the other, is used: the moulds in which the ice is to be formed being placed in the centre. The reduction of temperature produced by the freezing mixture in the outermost vessel cools the water in the second; and this, on salt being added, cools the third; and so on. In this way the cold is

very much intensified at the centre, and a low temperature can be produced independent of the initial temperature of the water. The number of rings employed varies according to the effect to be produced and the conditions under which the apparatus is applied. The annular vessels together with the ice moulds are carried in a wood casing supported on bearings, the only motive power required being that necessary to rotate the vessels slowly, so as to promote the solution of the salt.

Another form of apparatus, designed for continuous use on a large scale, consists of a vessel into which ammonium nitrate is automatically fed, and in which it enters into solution with water previously cooled in an interchanger by the spent liquor, after the latter has left the ice-making tanks or cooling rooms. The cold brine thus produced is circulated by a pump through the ice tanks, or through pipes placed in the rooms it is desired to cool; and is returned through the interchanger to an evaporating tank, where by means of heat the water is driven off and the salt recovered. This is practically Sir William Siemens' apparatus in a somewhat extended form. The cost of producing 15 tons of ice per 24 hours with such an apparatus of suitable capacity is stated at 7*s.* per ton, with good coals at 15*s.* a ton, and exclusive of depreciation and repairs. This however is probably much too low an estimate, being based upon the erroneous assumption that 1 lb. of coal is capable of evaporating 20 lbs. of water. Nearly the whole of the coal is used for evaporating the water in recovering the salt, the quantity being given at $2\frac{1}{2}$ tons of coal for every 15 tons of ice. If however this has been calculated on an evaporative duty of 20 lbs. of water per lb. of coal, the amount actually used will probably be about 5 tons of coal, which would make the cost per ton of ice 9*s.* 3*d.* instead of 7*s.* On the other hand it must be remembered that under certain climatic conditions much of the water could be evaporated in the open air, without the use of fuel; in which case the coal consumption, and therefore the cost of ice production, would be greatly lessened.

2. Machinery and Apparatus for Abstracting Heat by the Evaporation of a more or less Volatile Liquid.

When a liquid changes its physical condition and assumes the state of vapour, heat is absorbed in increasing the energy of the molecules. This heat is absorbed without change in sensible temperature; and the amount thus disposed of is usually called the latent heat of vaporisation. For different liquids different quantities of heat are required; and for the same liquid the amount varies somewhat according to the pressure at which vaporisation occurs. Other things being equal, the liquid with the highest latent heat will be the best refrigerant, because for a given abstraction of heat the least weight of liquid will be required, and therefore the power expended in working the machine will be the least. The principal systems in which the evaporation of liquids is employed may be treated under the following subdivisions:—

A. Apparatus in which the refrigerating agent is rejected along with the heat it has acquired.

B. Machines in which heat only is rejected, the refrigerating agent being restored to its original physical condition by means of mechanical compression and by cooling when under compression.

C. Apparatus in which heat only is rejected, by allowing the refrigerating agent to change its physical condition by entering into solution with a liquid, from which it is afterwards separated by evaporation and recovered.

D. Machinery and apparatus in which heat only is rejected, by changing the physical state of the refrigerating agent by a combination of both mechanical compression and solution, with cooling.

System A.—This is generally known as the vacuum process; for as the refrigerating agent itself is rejected, the only agent of a sufficiently inexpensive character to be employed is water, and this, owing to its high boiling point, requires the maintenance of a high degree of vacuum in order to produce ebullition at the proper

temperature. In Fig. 1, Plate 52, are shown graphically the vapour tensions of water at temperatures up to boiling point at atmospheric pressure (the actual figures being given in the appended Table 2, page 241); from which it will be seen that at 32° Fahr. the tension is only 0·089 lb. per square inch. In ice-making therefore a degree of vacuum must be maintained at least as high as this.

The earliest machine of this kind appears to have been made in 1755 by Dr. Cullen, who produced the vacuum by means of an air-pump. In 1810 Leslie, combining with the air-pump a vessel containing strong sulphuric acid, for absorbing the vapour from the air drawn over and so assisting the pump, succeeded in producing an apparatus by means of which 1 to 1½ lbs. of ice could be made in a single operation. Vallance and Kingsford followed later, but without practical results; and Carré many years afterwards embodied the same principle in a machine for cooling and for making small quantities of ice, chiefly for domestic purposes. His machine, which is still sometimes used, consists of a small vertical vacuum-pump worked by hand, either by a lever or by a crank, which exhausts the air from the carafe or decanter containing the water or liquid to be frozen or cooled. Between the pump and the water vessel is a lead cylinder, three-quarters full of sulphuric acid, over which the air, and with it the vapour given off from the liquid, is caused to pass on its way to the pump. The vacuum thus produced causes a rapid evaporation, which quickly lowers the temperature of the water; and, if the action is prolonged for about four or five minutes, the water becomes frozen into a block of porous opaque ice. The charge of acid is about 4½ pints, and it is said that from 50 to 60 carafes of about a pint each can be frozen with one charge. So long as the joints are all tight, and the pump is in good order, this apparatus works well; but in practice it has been found troublesome and unreliable, and consequently has never come into anything like general use.

In 1878 Franz Windhausen of Berlin patented a compound vacuum-pump for producing ice direct from water, on a large scale, without the employment of sulphuric acid; and also an arrangement in which sulphuric acid could be used, the acid being cooled by water

during its absorption of the vapour, and afterwards concentrated, so that a fresh supply was rendered unnecessary. This apparatus was improved on in 1880; and in 1881 a machine nominally capable of producing from 12 to 15 tons of ice per 24 hours was put to work experimentally at the Aylesbury Dairy at Bayswater, being afterwards removed to Lillie Road, where it now is. The installation was fully described and illustrated by Carl Pieper in a paper read before the Society of Engineers in November 1882, and by Dr. John Hopkinson at the Society of Arts about the same time.* It consists of six slightly tapered ice-forming vessels of cast iron, of circular cross-section, closed at their bottom ends by hinged doors with air-tight joints, into which water is allowed to flow at a regular rate through suitable nozzles, the cylinders being steam-jacketed in order to allow the ice to be readily discharged. The upper parts of these vessels communicate with the pump through a long horizontal iron vessel of circular section containing sulphuric acid, which, when the machine is in operation, is kept in continual agitation by means of revolving arms. The acid vessel is surrounded with cold water, which carries off most of the heat liberated during the absorption of the vapour. The pump has two cylinders, one double-acting of large size, and a smaller single-acting one. The capacities of these cylinders per revolution are as 62 to 1. The air and whatever vapour has passed the acid are drawn into the large pump, which partially compresses and delivers them into a condenser. Here part of the vapour is condensed by the action of cold water, the remainder passing along with the air to the second pump, where they are compressed up to atmospheric tension and discharged. The advantage gained by the use of a compound pump is due to the action of the intermediate condenser, and to the compression being performed in two stages, by which the losses from the clearance spaces in the large pump are rendered much less than they would be if compression to atmospheric pressure were accomplished in a single operation. The effect of the pump is said to be such that a vacuum of half a millimetre of mercury or about 0·0097 lb. per square inch can be

* Transactions of the Society of Engineers, 1882, page 145; Journal of the Society of Arts, 1882, vol. 31, page 20.

continuously maintained: though in actual work about 2½ millimetres or 0·0484 lb. per square inch is as low as is necessary. The concentration of the acid is effected in a lead-lined vessel, in which is a coil of lead piping heated by steam, the pressure in the vessel being kept down by means of an ordinary air-pump. No acid pump is needed, as the transfer from one vessel to another is effected by the pressure of the atmosphere. The comparatively cool weak acid on its way to the concentrator is heated in an interchanger by the strong acid returning from the concentrator. Six blocks of ice, each weighing about 560 lbs., are formed in about sixty minutes after starting. The charge of acid is said to serve for four makings of ice, after which it becomes too weak and requires to be concentrated.

The water being admitted into the ice-forming vessels in fine streams offers a large surface for evaporation, and is almost immediately converted into small globules of ice, which fall to the bottom and become cemented together by the freezing of a certain quantity of water that collects there. This water being in a violent state of ebullition, the ice so formed is not solid, but contains spaces or blow-holes, which, as soon as the block is discharged from the vessel, become filled with air and cause opacity. Several attempts have been made to produce transparent ice by the direct vacuum process, but so far without success. Distilled water or water deprived of air has been tried, and hydraulic pressure has been used for compressing the porous opaque blocks; but neither plan has been found practicable commercially. It would appear indeed that the only way to make clear ice by the vacuum process is by forming it in moulds or cells, subjected externally to the action of brine previously cooled by the evaporation of a portion of its water. The cost in this case would necessarily be greater; but the ice would be solid and transparent, and would consequently have a higher commercial value.

The latent heat of liquefaction of water being 142·6, the total heat to be abstracted in order to produce 1 ton of ice from 1 ton of water at 60° Fahr. is 382,144 units. Taking the latent heat of vaporisation of water at 32° Fahr. to be 1091·7, it is obvious that 350 lbs. must be evaporated to make the ton of ice. But in

addition the sensible heat of the evaporated water, which entering at 60° would leave at about 32°, would have to be taken off; and this would require the evaporation of about 9¼ lbs. more, making a total of about 360 lbs., without allowance for loss by heat entering from without, which would be considerable. The total water actually used is given by Mr. Pieper at from 10 to 12 tons per ton of ice, including the quantity required for cooling purposes. The fuel consumption is stated to be 180 lbs. of coal per ton of ice; but the author understands a much larger quantity is actually required. It is consumed in generating steam for driving the vacuum pump and the concentrator air-pump, and for evaporating the water absorbed by the acid. According to Dr. Hopkinson, the cost of making 1 ton of opaque ice is 4*s.*; but the author believes experience has shown that a much higher figure is required to cover the necessary expenses for repairs and maintenance, which in some parts of the apparatus are very heavy. Windhausen's machine has not met with any extended application in this country, owing no doubt to the opaque and porous condition of the ice produced by it, and to the large and cumbrous nature of the plant, which must doubtless require great care and supervision in working.

In 1878 James Harrison patented a vacuum apparatus for refrigerating liquids by their own partial evaporation, and for making ice. Its chief feature is the revolving cylinder or pump, shown in section in Fig. 3, Plate 53, which affords a simple and efficient means of exhausting large volumes of vapour of low tension, without incurring the loss from friction of ordinary piston-packings, and the trouble of keeping them tight and in good working order, while at the same time the first cost is much reduced. The pump consists of a hollow iron cylinder, revolving on a horizontal axis, and divided into compartments by longitudinal partitions of L section. It is partially filled with a non-evaporable liquid, or one which evaporates only at a temperature considerably in excess of that at which the refrigerating liquid is evaporated, and which is also chemically neutral to the vapour that is brought in contact with it. In practice oil is the liquid used. The refrigerating or ice-making vessels, of any convenient form, are connected by a pipe with one end of a fixed

hollow axle on which the cylinder revolves; and inside the cylinder another pipe rises up above the level of the liquid, the longitudinal partitions being stopped short at one end to enable this to be done. The compartments move round mouth downwards, carrying with them the vapour with which they are charged, and compressing it to an extent measured by the distance they dip below the surface of the liquid; until, when the lowest position is approached, the compressed vapour is liberated, and rises into a fixed hood near the centre, in communication with a second hollow axle at the opposite end of the cylinder to that at which the vapour enters. Through this second axle the compressed vapour passes to a surface evaporative condenser, in which it is partly condensed by the combined action of direct cooling and of the partial evaporation of water trickling over the surface: the water of condensation together with any air being then compressed to the tension of the atmosphere by a small pump, and discharged. By this process the author is informed it is expected to produce opaque ice on a large scale at a cost of about 1*s.* per ton. The fuel consumption will certainly be very small, because friction, which is a large item in the Windhausen apparatus, is here to a large extent eliminated. There would also be a saving of all the fuel used in concentrating the acid, and of much of the water required for cooling purposes, besides a reduction in the first cost of the plant and in the expense of maintenance.

System B.—This is known as the compression process, and is used with liquids whose vapours condense under pressure at ordinary temperatures. Although prior to 1834 several suggestions had been made with regard to the production of ice and the cooling of liquids by the evaporation of a more volatile liquid than water, the author believes that the first machine really constructed and put to work was made by John Hague in that year, from the designs of Jacob Perkins. According to Sir Frederick Bramwell* the liquid used was one arising from the destructive distillation of caoutchouc. The machine, which so far as the author is aware was never put to work

* Journal of the Society of Arts, 1882, vol. 31, page 77.

outside of the factory where it was constructed, is shown in section in Fig. 4, Plate 53. The water to be frozen was placed in the jacketed copper pan A, the jacket being partially filled with the volatile liquid, and carefully protected on the outside with a covering of non-conducting material. A pump P drew off the vapour from the jacket, and delivered it compressed into a worm W, around which cooling water was circulated, the pressure being such as to cause liquefaction. The liquid collected at the bottom of the worm, and returned to the jacket through the pipe D, to be again evaporated. This apparatus, though in some respects crude, is yet the parent of all compression machines used at the present time, the only improvements made since the year 1834 having been in matters of constructive detail.

The next advance was made in 1856 and 1857 by James Harrison, who brought out a machine embodying the same principles as that of Perkins, but worked out on a larger and more practical scale. This machine was constructed for the inventor by the late Mr. Siebe, and was the first ice-making apparatus that really came into practical use in this country and was employed for commercial purposes. An improved apparatus of this kind, in which sulphuric ether is used as the refrigerating agent, is still manufactured by Messrs. Siebe Gorman and Co. The vapour tensions of sulphuric ether are shown graphically in Fig. 1, Plate 52, and are also given in the appended Table 2. It is a not very volatile liquid, of specific gravity 0·720, having a latent heat of vaporisation of 165, and a specific gravity of vapour of 2·24 compared with air. Its boiling point at atmospheric pressure is 96° Fahr. Messrs. Siebe Gorman and Co.'s machine, applied to the manufacture of clear ice, is shown in elevation and plan in Figs. 6 and 7, Plate 54. It consists of a refrigerator R, a water-jacketed pump P, driven by the surface-condensing steam-engine E, an ether condenser D, and ice-making tanks T containing copper moulds, around which brine cooled to a low temperature in the refrigerator is circulated by the pump C. The refrigerator R is a cylindrical vessel of sheet copper, containing clusters of horizontal solid-drawn copper tubes, through which the brine successively circulates. The shell is connected with the pump P by a pipe, the liquid ether from the condenser being

admitted through a small pipe having a cock K, which is so adjusted as to pass the precise weight of ether that the pump P will draw off. What this weight is depends entirely on the pressure at which evaporation occurs; the greater the density of the vapour, the greater being the weight drawn off at each revolution of the pump. The pressure at which evaporation occurs is defined by the temperature to which it is desired to reduce the brine, the boiling point of the ether being regulated so as to give the required reduction of temperature and no more; otherwise the apparatus would not work up to its full capacity. The condenser D consists of a cluster of solid-drawn copper tubes, placed horizontally in a wood tank, through which cooling water is circulated, the amount of water required in this country being about 150 gallons per hour for every ton of ice made per twenty-four hours. With the temperature of cooling water available here, liquefaction generally occurs at a pressure of about 3 lbs. per square inch above the atmosphere; but in a warm climate the pressure needed may reach as much as 10 or even 12 lbs.

In the apparatus illustrated in Figs. 6 and 7, Plate 54, the ice is made in cans or moulds, as shown in section in Fig. 8. The moulds M, of sheet copper or steel, are filled with the water to be frozen, and are suspended in a tank, through which is kept up a circulation of cold brine from the refrigerator. As soon as the ice I is formed, the moulds are removed and dipped for a few minutes in warm water to loosen the ice, which is then turned out. The sizes of the moulds vary a good deal, according to the capacity of the machine, and the purpose for which the ice is to be used. A common plan is to commence with a thickness of 3 inches for a production of 1 ton per twenty-four hours, and to go up to 9 inches for 10 tons and upwards. The thickness exercises an important bearing upon the number of moulds to be employed for any given output; for, while a 3-inch block can be frozen in eight hours, one 9 inches thick will take about thirty-six hours. The time however varies also according to the temperature at which the brine is worked. For an ether machine, such as that just described, the brine temperature may be taken at from 10° to 15° Fahr.

Another method is that known as the cell system, which is shown in section in Fig. 9, Plate 54. This consists of series of cellular walls W of wrought or cast iron, placed from 12 to 16 inches apart, the space between each pair of walls being filled with the water to be frozen. The cooled brine circulates through the cells, the ice I gradually forming outside, and increasing in thickness until the two opposite layers meet and join together. If thinner blocks are required, freezing may be stopped at any time, and the ice removed. In order to detach the ice from the walls, it may either be left for a time after the circulation of the brine has been stopped, or a better and quicker plan is to pass some warmer brine through the cells.

In order to produce transparent ice, it is necessary that the water should be agitated during freezing, so as to allow the escape of the air set free. When moulds are used, Fig. 8, this is generally done by means of arms having a vertical or horizontal movement, which are either pushed up by the ice as it forms, leaving the block solid, or work backwards and forwards in the centre of the mould, dividing the block vertically into two equal pieces. With cells, Fig. 9, agitation is generally effected from the bottom by means of paddles. The ice which forms first on the sides of the moulds or cells is generally transparent enough even without agitation. The opacity gradually increases towards the centre, where the two layers meet and join together; agitation is therefore more necessary towards the end of the freezing process than at the beginning. As the quantity of air held in solution by water decreases as its temperature is raised, it is obvious that less agitation will be required in hot than in temperate climates; for this reason in India and elsewhere agitation is frequently dispensed with altogether.

Machines using ether as the refrigerating medium are also largely made by Messrs. Siddeley and Co. of Liverpool, and Messrs. West and Co. of Southwark; but they present no special features which are not embodied in the apparatus already described, the points of difference being in details to which it is not necessary to refer.

As already stated, the working pressure in the refrigerator must depend upon the extent of the reduction in temperature desired,

bearing in mind that, the higher the pressure, the greater will be the work that can be got out of any given capacity of pump. The liquefying pressure in the condenser depends on the temperature of the cooling water and on the quantity that is passed through in relation to the quantity of heat carried away; and this pressure determines the mechanical work to be expended. In any given machine the work may be accounted for as follows:—

Friction.
Heat rejected during compression.
Heat acquired by the refrigerating agent in passing through the pump.
Work expended in discharging the compressed vapour from the pump.

Against which must be set—

Work done by the vapour entering the pump.

Assuming that vapour alone enters the pump, the heat rejected in the condenser is:—

Heat of vaporisation acquired in the refrigerator, with the correction necessary for difference in pressure.
Heat acquired in the pump, less the amount due to the difference between the temperature at which liquefaction occurs and that at which the vapour entered the pump, and less also the amount lost by radiation and conduction between the pump and the condenser.

Though circumstances vary so much that no absolutely definite statement can be made as to the working of ether machines in general, the following particulars, taken from actual experiment in this country, will serve to show what may be expected under ordinary conditions:—

Production of ice, per twenty-four hours	15 tons.
„ „ per hour	1400 lbs.
Heat abstracted in ice-making, per hour	245,000 units.
Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water and for working cranes &c.	83 I.H.P.
Indicated horse-power in ether pump	46½ I.H.P.
Thermal equivalent of work in ether pump, per hour	119,261 units.
Ratio of work in pump to work in ice-making	1 to 2·05
Temperature of water entering condenser	52° Fahr.

Assuming the coal consumption per indicated horse-power to be 2 lbs. per hour, and the price of coal 15*s.* a ton, the total cost of producing transparent block ice in this country on the ether system with such a machine as that just referred to may be taken at about 5*s.* per ton, excluding allowance for repairs and depreciation. The production of ice would be about 8·3 tons per ton of coal.

For cooling water and other liquids, a similar machine is used to that shown in Figs. 6 and 7, Plate 54; but in this case the ice boxes are dispensed with, the liquid being passed direct through the refrigerator without the employment of brine.

Methylic ether, a liquid with a latent heat of vaporisation of 473 and which boils under atmospheric pressure at 10·5° below zero Fahr., has been employed by Tellier in apparatus of practically similar design to that used with ordinary ether. Its curve of vapour tensions is shown in Fig. 1, Plate 52. Tellier's apparatus has never come into use in this country, and need not be further dwelt on; for beyond the difference in size of pump, and the obvious alterations due to the higher working pressures, it presents no features of importance not shown by the machine in Figs. 6 and 7, Plate 54.

Some years ago Raoul Pictet, of Geneva, successfully introduced sulphur dioxide as a refrigerating agent; and in France a large number of his machines have been made and put to work. In this country also they have been used, but to a much smaller extent. The vapour tensions of sulphur dioxide are shown in Fig. 1, Plate 52. It is a liquid with a latent heat of vaporisation of 182, and under atmospheric pressure boils at 14° Fahr. This machine is also of similar design to those in which ether is employed; but Pictet combined the refrigerator with the ice-making tanks, the brine being circulated by means of a fan. In this way the space occupied was reduced, and the efficiency somewhat increased. The cost of producing ice by the Tellier and Pictet machines may be taken at practically the same as that by the ether process.

Some of the more volatile derivatives of coal tar have been used in compression machines, especially in the United States; but

it will be unnecessary to refer to them in detail, as their application has been exceedingly limited.

Anhydrous ammonia, which may now be obtained as an article of commerce, has of late years been very largely introduced as a refrigerating agent, more especially in Germany and in the United States. Under atmospheric pressure anhydrous liquid ammonia boils at 37·3° below zero Fahr., and under this condition its latent heat of vaporisation is 900. Its curve of vapour tension is shown in the diagram, Fig. 1, Plate 52. So far as the cycle of operation is concerned, it is precisely the same as for ether: the liquid is vaporised in the refrigerator by the action of the pump, which then compresses the vapour, and delivers it into the condenser at such pressure as to cause it to liquefy. In the construction of ammonia machines however there are two essential points of difference. For in the first place the pressure of the ammonia vapour is much higher than that of ether at the same temperatures, its tension at 60° Fahr. being 108 lbs. per square inch; and secondly, owing to the action of ammonia on copper, no brass or gun-metal can be used in any part with which the gas or liquid comes into contact. One of the chief difficulties encountered in the compression of ammonia is leakage at the pump gland. The gas is extremely searching, and even at the comparatively low pressure of 30 lbs. per square inch above the atmosphere it will readily find its way through an ordinary gland; while at the pressure existing in the condenser, which may be taken at from 150 to 180 lbs. per square inch, this tendency is of course much aggravated. In order to minimise the leakage and to simplify the construction of the gland, the pumps are frequently made single-acting, as in this way the gland is exposed only to the refrigerator pressure, which is seldom above 30 lbs. It is also usual for glycerine, or some lubricant that does not saponify with ammonia, to be injected into the pump, so as to form a liquid seal for the gland, and in some cases for the piston as well; this is the general practice in the United States. In Germany, on the other hand, where the compression machine has been very largely applied, the double-acting pump is more usual. To lessen

leakage, Linde provides a chamber in the gland box, into which glycerine or some suitable lubricant is constantly forced at a slightly greater pressure than that prevailing in the condenser, so that the tendency is for the lubricant to leak inwards, instead of ammonia outwards. Any lubricant that does get into the pump passes out with the ammonia, and is separated from it in a suitable vessel. Up to the present time, so few ammonia compression machines have been constructed in England, that as yet no general practice has been established; but on the whole the feeling seems to be in favour of the single-acting pump.

With regard to the other parts of the apparatus, but little need be said. Wrought-iron coils or zigzags are used for both the condenser and the refrigerator, their precise form depending on the fancy of the designer. The refrigerator is generally combined with the ice tanks, the cooling pipes being placed either below or at the side of the moulds, sometimes in a separate compartment and sometimes in the same tank. With the cell system shown in Fig. 9, Plate 54, an independent refrigerator is used, the cooled brine being circulated by a pump in a similar manner to that described for the ether system. Owing to the low temperature which may be attained by the use of ammonia, care has to be taken in the selection of a brine that will not congeal with the degree of cold to which it will be subjected. A solution of calcium or magnesium chloride in water is generally used.

The mechanical work expended in compressing ammonia may be accounted for in a precisely similar manner to that expended in the compression of ether. Notwithstanding that the degree of compression is so much greater with ammonia than with ether, the energy expended in compressing, heating, and delivering the gas is less, owing to the much smaller weight of ammonia required to produce a given refrigerating effect, the weights being in the inverse ratio of the heats of vaporisation, or as 1 to 5·45. For this reason the cost of making ice is much less with ammonia than with ether: one ton of coal being capable of producing as much as 12 tons of ice in well-constructed ammonia apparatus having a capacity of 15 tons per 24 hours. With coal at 15*s.* a ton, the cost of making ice by the

ammonia compression system may be taken at about 3*s*. 9*d*. per ton for a production of 15 tons per 24 hours, exclusive of allowances for repairs and depreciation.

Through the courtesy of the manager of the Linde British Ice Co., the author is enabled to give the following results of a test made by a committee of Bavarian engineers with a machine erected in a brewery in Germany. The test he believes was carried out in an impartial manner; and though it is not put forward by the Linde Co. as showing the results attained in the ordinary working of their machines, it will nevertheless be of interest as indicating what may be expected under the most favourable conditions.

Nominal capacity of machine, ice per 24 hours	24 tons.
Actual production of ice, per 24 hours	39·2 tons.
„ „ per hour	3659 lbs.
Heat abstracted in ice-making, per hour	731,800 units.
Indicated horse-power in steam cylinder, excluding that required for circulating the cooling water and for working cranes &c.	53 I.H.P.
Indicated horse-power in ammonia pump	38 I.H.P.
Thermal equivalent of work in ammonia pump, per hour . .	97,460 units.
Ratio of work in pump to work in ice-making	1 to 7·5
Total feed-water used in boiler, per 24 hours	26,754 lbs.
Ratio of coal consumed to ice made, taking an evaporation of 8 lbs. of water per lb. of coal	1 to 26·3

In this case the pumps were driven by a Sulzer engine, which developed one indicated horse-power with 21·8 lbs. of steam per hour, including the amount condensed in steam pipes.

Ammonia compression machines are manufactured in this country by Messrs. Siebe Gorman and Co., whose apparatus is shown in Figs. 10 and 11, Plate 55; by the Birmingham Refrigeration Co.; and by the Linde British Ice Co.

System C.—This is known as the absorption process, and was first applied by Carré about 1850. The principle employed is chemical or physical rather than mechanical, and depends on the fact that many vapours of low boiling-point are readily absorbed by water, but can be separated again by the application of heat to the mixed liquid. A considerable number of machines in which ammonia

was used in combination with water as an absorbent were made by Carré in France; but no very high degree of perfection was arrived at, owing to the impossibility of getting an anhydrous product of distillation: the ammonia distilled over containing about 25 per cent. of water, which caused a useless expenditure of heat during evaporation, and rendered the working of the apparatus intermittent.

In 1867 Rees Reece, taking advantage of the fact that two vapours of different boiling-points, when mixed, can be separated by means of fractional condensation, brought out an absorption machine in which the distillate was very nearly anhydrous. The action of the machine was briefly as follows. Ordinary liquid ammonia of commerce, of 0·880 specific gravity, was heated, and a mixed vapour of ammonia and water was driven off. By means of vessels termed the analyser and the rectifier, the bulk of the water was condensed at a comparatively high temperature, and run back to the generator; while the ammonia passed into a condenser, and there assumed the liquid form under the pressure produced by the heat in the generator, and the cooling action of water circulating outside the condenser tubes. The nearly anhydrous liquid was then utilised in a refrigerator in the ordinary way; but instead of the vapour being drawn off by a pump, it was absorbed by cold water or weak liquor in a vessel called an absorber, which was in communication with the refrigerator; and the strong liquor thus formed was pumped back to the generator, and used over again.

This apparatus was afterwards improved by Stanley, who introduced steam coils for causing the evaporation in the generator; and then by Pontifex and Wood, who have succeeded in bringing the absorption machine to a considerable state of efficiency. Their apparatus, as applied to the cooling of liquids, is shown in Fig. 5, Plate 53. G is the generator, containing the coils, to which steam is supplied from an ordinary boiler not shown; S is the analyser; D the rectifier and condenser; R the refrigerator or cooler, in which the nearly anhydrous ammonia obtained in the condenser is allowed to evaporate; A the absorber, through which weak liquor from the generator continually flows and absorbs the anhydrous vapour produced in the refrigerator; E the economiser or interchanger, by

means of which the cold strong liquor from the absorber is heated by the hot weak liquor passing from the generator to the absorber; and P are the pumps for forcing the strong liquor produced in the absorber back into the analyser, where, meeting with steam from the generator, the ammonia is again driven off: the process being thus carried on continuously.

Assuming the action of the economiser to be perfect—which of course is a condition never met with in practice—all the heat given out by the steam in the generator coils would be found in the water issuing from the condenser, less that portion directly lost by radiation and conduction. In this case the total heat expended would be that required to vaporise the ammonia, and the water, which in the form of steam unavoidably passes off with the ammonia to the rectifier and condenser; plus the heat lost by radiation and conduction. In the refrigerator the liquid ammonia in becoming vaporised will take up the precise quantity of heat that was given off during its cooling and liquefaction in the condenser, less the amount due to difference in pressure, and less also the small amount due to the difference in temperature between the vapour entering the condenser and that leaving the refrigerator. Again, when the vapour enters into solution with the weak liquor in the absorber, the heat taken up in the refrigerator is given to the cooling water, subject to slight corrections for differences of pressure and temperature. Supposing there were no losses therefore, the heat given up by the steam in the generator, plus that taken up by the ammonia in the refrigerator, would be precisely equal to the amount taken off by the cooling water from the condenser, plus that taken off from the absorber. The sources of loss are:—

Inefficiency of the economiser.

Radiation and conduction from all vessels and pipes that are above normal temperature.

Useless evaporation of water which passes into the rectifier and condenser.

Conduction of heat into all vessels and pipes that are below normal temperature.

Water passing into the refrigerator along with the liquid ammonia.

It will have been seen that the heat demanded from the steam is very much greater in the absorption system than in the compression.

This is chiefly due to the fact that in the absorption system the heat of vaporisation acquired in the refrigerator is rejected in the absorber: so that the whole heat of vaporisation, required to produce the ammonia vapour prior to condensation, has to be supplied by the steam. In the compression system, the vapour passes direct from the refrigerator to the pump, and power has to be expended merely in raising the pressure and temperature to a sufficient degree for enabling liquefaction to occur at ordinary temperatures. On the other hand a great advantage is gained in the absorption machine by using the direct heat of the steam, without first converting it into mechanical work; for in this way its latent heat of vaporisation can be utilised by condensing the steam in the coils and letting it escape in the form of water. Each lb. of steam passed through can thus be made to give up some 950 units of heat; while in a steam engine using 2 lbs. of coal per indicated horse-power per hour, about 160 units only are utilised per lb. of steam, without allowance for mechanical inefficiency. In the absorption machine also the cooling water has to take up about twice as much heat as in the compression system, owing to the ammonia being twice liquefied, namely once in the condenser and once in the absorber. It is usual to pass the cooling water first through the condenser and then through the absorber.

The cost of producing clear block ice in this country, with an absorption machine of 15 tons capacity per 24 hours, may be taken at about 4*s.* per ton, with good coals at 15*s.* per ton, exclusive of allowance for repairs and depreciation. About 10 tons of ice can be made per ton of coal consumed, assuming an evaporative duty of 8 lbs. of water per lb. of coal.

System D.—In this, which is known as the binary absorption system, liquefaction of the refrigerating agent is brought about partly by mechanical compression and partly by absorption; or else the refrigerating agent itself is a compound of two liquids, one of which liquefies at a comparatively low pressure, and then takes the other into solution by absorption.

An apparatus of the first kind was brought out in 1869 in Sydney by Messrs. Mort and Nicolle, who used ammonia, with water as an absorbent. The machine consisted of an evaporator or refrigerator, a pump, and an absorber. The evaporator was supplied with strong ammonia liquor, which was vaporised by means of the reduction of pressure induced by the pump, and so abstracted heat from the liquid to be cooled. The weak liquor passing out at the bottom of the evaporator was led by pipes to the pump, where it met with the ammonia vapour, along with which it was forced through cooling vessels under sufficient pressure to cause the solution of the ammonia; and the strong liquor thus formed was again passed into the evaporator. This machine was only used by the inventors in Australia, so far as the author is aware; and he has no particulars as to fuel consumption or cost of working. It was not likely however to be a very economical apparatus, because the whole of the water entering the evaporator with the ammonia had to be reduced in temperature, giving up its heat to the ammonia vapour, and to that extent preventing the performance of useful cooling work. But this disadvantage was in some degree compensated for by reducing the temperature of the strong liquor before it entered the evaporator, by means of an interchanger, through which the very cold weak liquor passed on its way to the pump.

In machines of the second kind, in which both liquids are evaporated at a low temperature, the foregoing objection does not exist; and though this mode of working has not as yet been introduced into this country, it has been successfully employed in the United States for several years by Messrs. De Motay and Rossi. The liquid used is a mixture of ordinary ether and sulphur dioxide, and has been termed ethylo-sulphurous dioxide: its adoption being decided on after a series of experiments with numerous other combinations of ethers and alcohols with acids. In these investigations it was found that liquid ether at ordinary temperatures possessed an absorbing power for sulphur dioxide amounting to some 300 times its own volume; while at 60° Fahr. the tension of the vapour given off from the binary liquid was below that of the atmosphere. In working, both liquids evaporate in the refrigerator, under the

influence of the pump; and in the condenser the pressure never exceeds that necessary to liquefy the ether. The compressing pump has less capacity than would be required for ether alone, but more than for pure sulphur dioxide. The author has no particulars as to the cost of making ice by this process; but he believes it to be somewhat less than with ether.

An interesting application of the binary system has lately been made by Raoul Pictet, who found that by combining carbon dioxide and sulphur dioxide he could obtain a liquid whose vapour tensions were not only very much less than those of carbon dioxide, but were actually below those of pure sulphur dioxide at temperatures above 78° Fahr. The curve for Pictet's liquid is shown in the diagram, Fig. 1, Plate 52. This is a most remarkable and unlooked-for result, and may open up the way for a much greater economy in ice production than has yet been attained. As to the results that have been obtained with this process, the author has no definite particulars; but he understands it is stated to give a production of 35 tons of ice per ton of coal.

3. Machinery by which a Gas is Compressed, partially Cooled while under compression, and further Cooled by subsequent Expansion.

This subject having been dealt with in a paper on "Machines for producing Cold Air" which the author had the honour to read before the members of this Institution in January 1881, the remarks under this head will therefore to a large extent be supplementary to that paper, and will refer chiefly to improvements which have been effected since that date. It will be convenient however, and will tend to a better appreciation of the subject, to present concisely some brief considerations respecting the physical laws relating to this system of refrigeration, even at the risk of repeating part of the matter touched upon in the previous paper.

The intrinsic energy of a permanent gas, or its capacity for performing work, depends entirely upon its temperature. Increase of pressure imparts no additional energy, but merely places the gas in such a condition relatively to some other pressure as to enable

advantage to be taken of its intrinsic energy by expansion. Thus a pound of air at ordinary atmospheric pressure has the same intrinsic energy as a pound of air at 50 lbs. pressure above the atmosphere, so long as their temperatures are the same; but in the former case no part of the energy can be made use of by expansion without the removal of at least a part of the equal and opposite resistance of the atmosphere, while in the latter case expansion can take place freely until the pressure is reduced to that of the atmosphere. As mechanical work and heat are mutually convertible, it is obvious that, if during expansion a gas is caused to perform work on a piston, its supply of heat must be drawn on to an extent measured by the thermal equivalent of the work done, provided no extraneous source of heat exists from which the deficiency can be made good; and the gas after expansion will be colder than it was before expansion. Expansion behind a piston without the addition of heat from any extraneous source is called adiabatic expansion; and the following are the relations between temperature, volume, and pressure for any two points in the same adiabatic curve:—

$$\frac{t}{t_1} = \left(\frac{v_1}{v}\right)^{\gamma - 1} = \left(\frac{p}{p_1}\right)^{\frac{\gamma - 1}{\gamma}}$$

where t and v and p denote absolute temperature, volume, and absolute pressure before expansion, and t_1 v_1 p_1 those after expansion, while γ is the ratio of the specific heat under constant pressure to that with constant volume. The results with regard to the expansion of dry air are shown graphically by the curve E F in Fig. 2, Plate 52: E D representing the initial volume at a pressure of 50 lbs. per square inch above the atmosphere and at a temperature of 70° Fahr., which is expanded down to the volume F B at atmospheric pressure, the temperature falling to − 115° Fahr. owing to the performance of the mechanical work represented by the area E F I K.

During adiabatic compression, the converse results take place, and the same relations exist between absolute temperature, volume, and absolute pressure, as during expansion: t_1 v_1 p_1 denoting those

before compression, and $t\ v\ p$ those after compression. On the diagram this is shown graphically by the curve A C, which is the adiabatic for the compression of the initial volume A B at atmospheric pressure and 70° Fahr., to 50 lbs. per square inch above the atmosphere, the temperature rising to 354° Fahr. owing to the acquirement of heat due to the performance of the mechanical work represented by the area A G J C. A E is the line of isothermal compression and expansion between the two points A and E.

In the succeeding remarks reference will be made to the use of ordinary atmospheric air alone; for although in one or two special instances this class of machinery has been applied to the cooling of some of the more volatile hydro-carbons, its almost universal application at the present time is for the cooling of air, which therefore will alone be dealt with.

The amount of aqueous vapour present in the atmosphere varies from that required to produce saturation down to about one-fifth of that quantity. At any given temperature a volume of saturated air can contain only one definite amount of vapour in solution; and if from any cause additional moisture be present, it cannot exist as vapour, but appears as water in the form of fog or mist. The temperature of saturation, or dew point, varies according to the quantity of vapour in solution: the smaller the quantity, the lower being the dew point. The capacity of air for holding moisture is also affected by pressure: a diminution in volume under constant temperature reducing this capacity in direct proportion.* In the former paper reference was made to various means that had been devised for ridding the air more or less completely of its contained moisture, in order to obviate as much as possible the practical evils resulting from its condensation and freezing: this being at that time considered one of the most important points in the construction of cold-air machinery. Since then however experience has demonstrated that these evils were

* For the quantity of vapour necessary to produce saturation, reference may be made to the table and formula given in the appendix to the paper on "Machines for producing Cold Air" (Proceedings 1881, page 122).

much exaggerated, and that the condensation of the vapour and deposition of the moisture in the ordinary cooling process after compression, which is common to every cold-air machine, are amply sufficient to prevent any serious deposition of ice about the valves and in the air passages: provided firstly that these valves and passages are well proportioned, and secondly that proper means are adopted for obtaining in the coolers a deposition of the condensed vapour, which would otherwise pass with the air into the expansion cylinder in the form of fog, and become converted into ice. Reference to the table shows that, if the compressed air be thoroughly deprived of its mechanically suspended moisture, the amount of vapour entering the expansion cylinder is extremely small. Another matter from which the mystery has now been dispelled is the meaning of the term "dry" air, so much used by the makers of cold-air machinery: this being a point that was just touched upon towards the close of the discussion upon the previous paper. No doubt it is still to a large extent popularly supposed that, unless the air be subjected in the machine to some special drying process, it will be delivered from the expansion cylinder in a moist or damp state, and in consequence be unfitted for use in the preservation of perishable food and for other purposes. But no such state could really exist; for whether the air be specially "dried" or not, its humidity when delivered from the expansion cylinder is precisely the same, so long as its temperature and pressure remain the same, inasmuch as in practice it is always in a saturated condition for that pressure and temperature. The difference lies in the amount of ice formed, which of course is greater if the amount of moisture entering the expansion cylinder is greater; but this quantity, as has been already stated, may in the author's opinion be brought down within perfectly convenient limits by a proper construction of the cooling vessels. In his latest machines therefore all special drying apparatus has been dispensed with: the air being simply compressed, passed through a surface cooler, and expanded back to atmospheric pressure. On the other hand Messrs. Haslam and Co. of Derby, and Messrs. J. and E. Hall of Dartford, still apply an interchanger, on somewhat the same principle as that previously described in connection with the Bell-Coleman machine

(Proceedings 1881, page 111); and it would be interesting if some definite particulars could be furnished to show what practical effect this interchanger really has.

Messrs. Hall's cold-air machine is of both horizontal and vertical type, the latter applying to the smaller sizes. In either case, when combined with a steam engine, it consists of three double-acting cylinders placed side by side, at the end of a frame or bedplate; the cylinders are furnished with the usual moving parts, and the connecting-rods work on three crank-pins on a common crank-shaft. One of the cylinders is used with steam in the ordinary manner, for giving the requisite motive power. Of the two others, one is for compressing and one for expanding the air. The coolers are of the multitubular type for surface cooling, and are placed below the bedplate or frame, an interchanger being also provided for still further reducing the temperature of the compressed air, by the action of the spent air from the storage chambers. The valves for the compression and expansion cylinders are slides of somewhat peculiar design, worked from a pair of weigh-bars, one for the main and the other for the expansion slides. The valves are usually placed on the under-side of the cylinders, which renders them rather difficult of access; but in the larger sizes of machines the cylinders are raised, and work down to the shaft at an angle, which gives a little more room below. In some of the later machines the valves are placed above the cylinders. The compressor is water-jacketed.

The Haslam dry-air refrigerator, which has been very largely adopted, is also made both horizontal and vertical, the horizontal type applying to large machines, as shown in Figs. 12 and 13, Plate 56, and the vertical to those of small size. The cylinders are double-acting, and their arrangement with regard to one another varies in different classes of machines. The compressor C is water-jacketed, and discharges into surface coolers R placed in the bed. The compressed air, after having been cooled in the ordinary way by water, is further reduced in temperature in an interchanger, by the action either of the spent cold air on its way from the chamber in which it has been utilised, or of the cold air as it leaves the expansion cylinder E; and in this manner a further

condensation and deposition of moisture are brought about. The expansion cylinder E presents no peculiarity in design, with the exception of the exhaust valves, which are separate from those admitting the air, and are so arranged as to offer as little obstruction as possible to the passage of the air. The Haslam Co. also manufacture the Bell-Coleman machine, which was described in the author's previous paper (Proceedings 1881, page 111).

A horizontal dry-air refrigerator of the author's design, of the type used for delivering from 20,000 to 60,000 cubic feet of cold air per hour, is shown in Figs. 14 and 15, Plate 57; and a section through the compression and expansion cylinders and valves is given in Fig. 16. The compressor C is double-acting, and the expansion cylinder E single-acting. They are placed close together, tandem fashion, leaving room for examination of the piston, with one rod common to both cylinders. In this way the coldest part of the expansion cylinder is removed from the hottest part of the compressor. The air-valves, shown black in the section, Fig. 16, are circular slides of phosphor-bronze, actuated by eccentrics in the usual way. This kind of valve enables the ports to be made very short and direct; and besides being noiseless in action, it allows of a high piston-speed being attained. No trouble has been experienced with regard to wear, not a single case having occurred in which the valves have had to be replaced, notwithstanding that some have been in almost constant work since 1882. The air enters the compressor C by the pipes A, and after being compressed passes by the pipe B to the coolers RR, which are placed in the bedplate, and consist of a couple of iron vessels containing clusters of solid-drawn Muntz-metal tubes of $\frac{3}{4}$-inch external diameter. Water is circulated through the inside of the tubes by the pump P, the supply passing in by the pipe D, through the tubes, and away by the pipe F to the compressor jacket, whence it escapes by the pipe H. The water condensed and deposited from the air in the coolers is blown off from time to time by means of drain cocks, or may be discharged automatically. The compressed air passes through one cooler and returns through the second, being cooled to within some 5° or 6°

of the initial temperature of the cooling water, which circulates in a direction opposed to that of the air. The quantity of water required is at the rate of from 30 to 40 gallons for every 1000 cubic feet of cold air discharged, that is, from three to four times the weight of the air; but the quantity varies in different machines according to the efficiency of the apparatus. From the coolers, the air passes by the pipe I to the expansion cylinder E; and after performing work upon the piston, and returning about 60 per cent. of the power expended in its compression, it is exhausted from the passage K, having become cooled down to from 70° to 90° below zero Fahr. The steam cylinder L is overhung from strong brackets cast on the bedplate, and is arranged so that a jet or surface condenser can be placed below, with an air-pump worked from a continuation of the piston-rod; the space occupied is thus practically the same, whether the engine is non-condensing, as shown in Plate 57, or condensing. The arrangement also lends itself readily to the application of a second steam cylinder, tandem fashion, for working on the compound principle, as shown in Figs. 17 and 18, Plates 58 and 59. In this case the surface-condenser C is placed below the high-pressure cylinder H, the air-pump P being driven from a crank-pin fixed in the fly-wheel. The same water serves both for cooling the air and for condensing the steam, passing first through the coolers R, and then through the surface-condenser C.

For land machines to deliver more than 60,000 cubic feet of cold air per hour, the vertical type is adopted, and the compressor is made single-acting as well as the expansion cylinder, while a horizontal compound condensing steam-engine is used for giving the necessary motive power. A machine to deliver 285,000 cubic feet of cold air per hour, for cooling a large market, is now being designed in this way. The compressor is furnished with an internal pipe, from which a spray of cold water continually plays on the back of the piston and on the sides of the cylinder, but never comes in contact with the air itself.

In order to secure compactness and simplicity, all machines delivering less than 20,000 cubic feet of cold air per hour are made of the type shown in Figs. 19 and 20, Plate 60, the compressors

being single-acting. A section through the air cylinders of such a machine is given in Fig. 21. The smaller sizes are very frequently made on the vertical plan, for use both on land and on board ship. A steam-driven vertical machine is shown in Figs. 22 and 23, Plate 61. The design is practically the same as that of the horizontal machines; but in the vertical type the coolers R are cast in one piece with the frame, instead of being separate. In Figs. 24 and 25 is shown a vertical machine of similar design, but arranged for being driven by a belt.

The main objects kept in view by the author in designing all the foregoing machines are:—economy of production, efficiency, and simplicity. Some thirty of these refrigerators of one form or the other have now been made and put to work since 1884; and in not one single instance has any breakdown occurred in working, nor have any repairs been required beyond those that would have been necessary to an ordinary steam engine of good construction. In many cases machines made in England have been packed and shipped to Australia, and to North and South America and other foreign countries, where they have been erected and put to work without the assistance of any skilled labour from this country.

With regard to the power expended in cooling air on this plan, it may be stated that, in the best machines of large size now made, a weight of 1000 lbs. of air per hour can be reduced from 60° above to 80° below zero, with cooling water at 60° Fahr., with the expenditure of about 18 indicated horse-power. This is equal to an abstraction of 916 units per lb. of coal, with an engine using 2 lbs. of coal per indicated horse-power per hour.

4. Considerations as to the Applications of the Various Systems.

Under this head it is not intended to deal with the class of apparatus first described — for abstracting heat by the rapid melting of a solid: inasmuch as, excepting for domestic purposes in localities where other ice is not available, its application is wholly special and very limited, being confined almost entirely to the laboratory. Nor in regard to the machinery and apparatus in the

second class—for abstracting heat by the evaporation of a more or less volatile liquid — need much be said, so far as ice-making and ordinary cooling are concerned; the various systems have already been explained in considerable detail, and sufficient information has been given upon which to base an estimate as to their economical application under any stated conditions. It is therefore chiefly with the machinery described in the third class that the present considerations will deal:—namely machinery by which a gas is compressed, partially cooled while under compression, and further cooled by subsequent expansion in the performance of work.

Probably the earliest application of a refrigerating machine to manufacturing purposes was in 1861, when one of Harrison's ether machines was used by Mr. A. C. Kirk for the extraction of solid paraffin from shale oil. Since then the manufacture of paraffin has been developed to a large extent, and at the present time there are very few works engaged in its production without a refrigerating machine of one kind or another.* For the cooling of worts and of fermenting beer in breweries, refrigerating machines are largely employed. With English beer, which it is not necessary to cool below 50° Fahr., the general practice is to reduce the temperature of the cooling liquor by passing it through the refrigerator of the machine, the cooled liquor being afterwards used in an ordinary brewer's refrigerator. For lager beer however, which is fermented at about 40° Fahr., the liquor is generally cooled by means of brine, and the temperature is brought down nearly to freezing-point. The same machine is in this country frequently employed for circulating cooled brine through a series of pipes above the fermenting tuns as well as for cooling the liquor; while in lager-beer breweries the whole of the fermenting rooms and stores are kept, the former at about 42° Fahr., and the latter at about 38° Fahr., by means of cold brine circulating through pipes placed either on the ceiling or around the walls.

---

* Full information in regard to the most recent practice in paraffin cooling will be found in the Journal of the Society of Chemical Industry, 29 May and 30 Nov. 1885, which contains papers by Mr. Beilby describing the cooling machinery erected at the Oakbank Oil Works.

For breweries, as well as for paraffin extraction, there can be no doubt that the most suitable machines to employ are those in which the cold is produced by the evaporation of a volatile liquid. Notwithstanding this, air-refrigerating machines have been applied for both purposes in certain special cases, and have given good results, though at a larger expenditure of fuel. There are many instances however in which the extra cost of fuel may be more than counterbalanced by the advantages resulting from simplicity and compactness, and from the absence of all inflammable or corrosive chemicals. Besides this the facility of application of cold-air machines is much beyond that of any other refrigerator. For these reasons they have been applied in dairies, and in butterine works: in the latter case an additional advantage being gained from the rapidity with which the cooling can be accomplished, owing to the extremely low temperature at which the air is delivered from the machine.

The most extensive application of dry-air refrigerators however has been to the preservation of meat and other perishable foods. Explanations with regard to the general question of preservation by cold have already been fully gone into by the author in a paper on the "Preservation of Foods by Cold" read before the Health Congress at Brighton in December 1881; and it will therefore suffice here to state that, although it had long been known that at low temperatures the decomposition of animal matter was arrested for an almost indefinite period, yet the practical realisation of preservation by cold was prevented from being carried out for want of a simple and efficient means of artificial refrigeration. The attempts that had been made to produce a refrigerated atmosphere by means of ice had not given satisfactory results, owing no doubt to the moist state of the air, which, cooled by contact with melting ice, was necessarily saturated, and brought about a musty taste and loss of flavour in the meat preserved in it. In 1878 however, upon the successful development of the cold-air machine, it became possible to produce a cold atmosphere, which even at a temperature of from 35° to 40° never contained more than from 50 to 60 per cent. of the moisture required to saturate it. Under this condition all danger from excess of moisture as well as from excessive dryness was

avoided; and the dry-air refrigerator was therefore speedily adopted for preservative purposes.

Machines in which cold is produced by the evaporation of a volatile liquid have also been applied for preserving perishable foods. This has been done, either by cooling the rooms direct by means of overhead pipes through which the cooled brine is circulated; or else by causing a current of air from a fan to impinge against surfaces cooled by an internal circulation of brine, and by then passing the cooled air into the storage rooms.*

As to whether the air machine or that employing a volatile liquid is the best and most suitable, no general rule can be laid down. The simplicity, compactness, and readiness of application of the former have secured it a ready adoption in many cases where chemical machines would have been wholly inadmissible; but on the other hand the author considers that air machines have frequently been entirely misapplied. For use on board ship there can probably be no difference of opinion; and nearly the whole of the meat now imported into this country in a cooled or frozen condition is preserved by means of dry-air refrigerators, while in only one or two cases is a portion of it chilled and frozen on land by chemical machines.

The means adopted for the freezing and preservation of meat are very simple. They consist in lining the room, or the hold of the vessel, with material as impervious to heat as practicable. The construction of the lining is altered in different cases according to circumstances and to fancy; but it may be taken that an outer and inner layer of tongued and grooved boards 1 inch or $1\frac{1}{2}$ inches thick, with a 9-inch space between filled with charcoal, form a fairly good protection; while in some cases silicate cotton may be used with advantage instead of charcoal. A little extra care and expense bestowed on the insulation of a chamber are soon repaid; for when the contents of the chamber are once reduced to the required temperature, the refrigerating machine has nothing further to do than to neutralise

* An apparatus on the latter plan by Mr. Chambers of New Zealand was fully described and illustrated in "The Engineer" of 14 August 1885, page 130.

the heat passing through the walls: so that, the more perfect the insulation, the greater is the saving in fuel, in wear and tear of machinery, and in attendance. The cold air from the machine is usually admitted by ducts placed near the ceiling; and after performing its cooling work it is led back to the compressor, to be used over again with the addition of a small amount of fresh air. In freezing, a temperature of about 10° Fahr. or even lower should be maintained, and the carcasses should be hung so that the air can circulate freely around them. If however the meat has previously been frozen, as is generally the case with the cargoes brought from abroad, which are to a large extent frozen on shore, the carcasses are best packed as close together as possible, taking care to avoid injury through bruising, and to see that a free space is left for the cold air to circulate between the meat and the inner lining of the chamber. The temperature in this case need only be maintained low enough to leave a sufficient margin in case of the machinery having to be stopped for any slight adjustment or for oiling.

The capacity of a machine to be applied in any given case is determined by a consideration first of the cooling work to be performed on the material contained in the chamber; and secondly of the amount of heat that will pass into the chamber from without. With regard to the first, nothing need be said here. The second quantity depends upon the area of the walls, floor, and ceiling, their construction, and the difference between the minimum internal and maximum external temperature. Experience has of course laid down certain general rules; but there are always special cases arising which require special treatment, and which can only be considered on the basis here set forth.

The trade in frozen meat has already necessitated the establishment of large stores, where the carcasses are received and kept until they are required for consumption. A number of retail butchers also are now adopting cold stores of their own; and in Fig. 26, Plate 62, is shown in section such a storage arrangement carried out in the vaults in Leadenhall Market for the preservation of about 20 tons of meat, partly frozen and partly unfrozen. A vertical dry-air machine, such as is shown in Figs. 24 and 25,

Plate 61, is driven by an Otto gas engine, and by working from three to six hours per day supplies sufficient cold air for the four chambers. The temperature rises a few degrees during the night, and between Saturday night and Monday morning; but this is not found to be any disadvantage, and it has never yet been necessary to run the machine on a Sunday. The same water that is used for cooling the air cools also the gas-engine cylinder, and is afterwards used for heating the offices. The cost of the gas in this case is 1*s.* 3*d.* per hour. In view of the increasing demand for installations of this kind, the author has made arrangements with Messrs. Crossley Brothers to manufacture his dry-air machine in combination with the Otto gas engine, in a form somewhat similar to that shown in Figs. 19 and 20, Plate 60, the gas engine simply taking the place of the steam engine there shown. In this way the cost will be reduced; and space also, which is generally very limited, will be saved. Similar installations to that shown in Fig. 26, Plate 62, have been erected for poulterers, game dealers, and butter salesmen, but need not be further referred to.

In addition to the importation of dead meat, refrigerating machines of the horizontal kind shown in the diagrams have been applied for supplying fresh cool air for the ventilation of ships' holds in which live cattle are carried. In this way a temperature of 100° Fahr. has been reduced to 70° in the height of summer, and the loss of cattle has been entirely prevented. No doubt the same system could be equally well applied for the cooling and ventilation of buildings; but so far as the author is aware it has not yet been tried.

In Fig. 27, Plate 62, is shown a plan, partly in section, of an arrangement on board a passenger vessel for making ice, preserving meat, game, fish, vegetables, and other perishable foods, and cooling water, wine, beer, aërated waters, &c. This is a plan frequently carried out in large passenger vessels, and was introduced, the author believes, by Mr. Manuel, the engineering superintendent of the Peninsular and Oriental Company. The particular arrangement illustrated is one adopted in connection with a vertical steam-driven machine such as that shown in Figs. 22 and 23, Plate 61. The course of the cold air is indicated by arrows. In case of the vegetable

room becoming too cold, ducts are provided by which the air can be led direct from the meat chamber to the machine. A somewhat similar arrangement of refrigerating plant is used in hotels; and the author's machines have been successfully applied for this purpose in the United States, though not as yet in this country.

A recent application, also worthy of notice, is for preserving fish on board steam-trawlers and on shore. Last year two of the author's vertical machines were supplied for this purpose, one on a steam-trawler and one on a carrier, for use off the coast of Brazil, almost under the equator, in a climate where fish was hardly known as an article of diet, owing to the previously insuperable difficulties of preserving it in a sufficiently fresh state. The fish as soon as caught are placed on trays in an insulated room maintained at a temperature of about 35° Fahr. The experiment has been perfectly successful, and a further order for similar machinery is now being executed.

In 1882 dry-air refrigerators were first applied to the cooling of chocolate by Messrs. J. S. Fry and Sons of Bristol, who adopted one of the author's horizontal machines with the double-expansion arrangement described in his previous paper. Since then a number of similar machines have been applied for the same purpose in different parts of Europe and in the United States; and works which had to be entirely stopped in summer are now carried on during the whole year. The preservation of yeast, the cooling of gelatine dry plates, and of fresh-killed meat in slaughter houses, and the freezing of tongues in South America for exportation, have all been satisfactorily accomplished by the dry-air machine.

A rather remarkable application of refrigeration was made towards the close of last year by Captain Lindmark, of the Swedish Royal Engineers, who was engaged in the construction of a tunnel for foot passengers through a hill in Stockholm, on the top of which were built residential houses, as shown in Fig. 30, Plate 63. The workmen came upon some ground, consisting of gravel mixed with clay and water, which had so little cohesion that the ordinary method of excavation had to be abandoned and the works stopped, owing to a subsidence in the earth above, which endangered the safety of the

houses. Underpinning was out of the question, on account of the great expense. Under these circumstances it was decided to freeze the running ground, and to use cold air for the purpose as being most readily applied. One of the author's horizontal machines, capable of delivering 25,000 cubic feet of air per hour, was accordingly supplied by Messrs. Siebe Gorman and Co., and was erected in the tunnel as close as possible to the required spot. The arrangement is shown in Figs. 31 and 32. The innermost end of the tunnel next the face was formed into a freezing chamber by means of a partition wall P, which was made of a double layer of wood filled in between with charcoal. In the middle of last September the works were resumed. After the refrigerator had run for sixty hours continuously, the gravel was frozen into a hard mass to a depth varying from five feet near the bottom of the tunnel to one foot near the top. At the crown no freezing took place; and though the temperature at the bottom of the chamber was as low as 40° below zero Fahr., a thermometer placed at the top, 16 feet above the floor, indicated 32° above zero. This circumstance however was an advantage rather than otherwise, because in any case the roof would have had to be supported by planking, which would have been difficult to drive into the gravel had it been actually frozen at that part. The work was proceeded with in lengths of 5 feet, the excavation commencing at the top; and a temporary iron wall W made up of plates 12 inches square, as shown in Fig. 32 and also in Figs. 28 and 29, Plate 62, was built in against the face from the top downwards as the cutting away of the gravel proceeded. For 8 to 10 feet up from the bottom no protection was needed, as the frozen gravel formed such a hard solid mass that it had to be removed with special tools. After once fairly starting, it was sufficient to run the cold-air machine on the average from ten to twelve hours every night, excepting after heavy rains, when much water percolated through the gravel. The machine worked all the time without a single hitch, and delivered the air at a temperature of 67° below zero Fahr. The temperature of the freezing chamber was generally from 6° to 15° below zero Fahr. after twelve hours' running; but it soon rose to freezing point when the men began to work. After two 5-feet lengths had been excavated,

the partition wall P was removed forward; the capacity of the freezing chamber thus varied from 3,000 to 6,000 cubic feet. The arching of the tunnel was completed as rapidly as possible close up to the temporary iron wall W, while the ground was still frozen. This method of driving the tunnel was employed through a distance of about 80 feet with entire success. In the residential house to the north, neither subsidence nor cracks were perceptible three months after the tunnel was completed at this point. In the house to the south, the front has subsided about an inch, causing some small cracks in the walls; but this house was not so well built as the other, subsidences having taken place in it before the tunnel was commenced. The daily progress while using the freezing process averaged about 1 foot.*

Although this is the first instance in which a dry-air refrigerator has been applied for the freezing of running ground, it is not the first in which refrigeration has been used for that purpose. As early as 1862 an ether machine was constructed by Messrs. Siebe Gorman and Co. for freezing a quicksand met with in sinking a well. In that case pipes formed into a coil of larger diameter than the lining of the well were sunk into the quicksand, which was then frozen solid by circulating cold brine through the pipes. The excavation was then proceeded with, the lining put in, the circulation of brine stopped, and the coil removed. The same plan has recently been adopted by Mr. Poetsch in Germany in connection with the sinking of colliery shafts; but instead of a coil, a series of vertical iron pipes are used, arranged in a circle, the effect of course being precisely the same.† For driving the Stockholm tunnel however, it is difficult to see how freezing by means of brine could have been applied, the excavation being horizontal instead of vertical.

---

* A full description of the construction of this tunnel is given in "The Engineer" of 9 April 1886, page 282.

† Further particulars of Poetsch's process are given in "The Engineer" of 30 November 1883, page 417.

TABLE 1.

Freezing Mixtures.

Composition by weight.	*Reduction of Temperature in degrees Fahr.*
Ammonium chloride . 5 parts Potassium nitrate . 5 „ Water . . . 16 „	From + 50° to + 10° = 40°
Ammonium nitrate . 1 part Water . . . 1 „	From + 50° to + 4° = 46°
Ammonium chloride . 5 parts Potassium nitrate . 5 „ Sodium sulphate . 8 „ Water . . . 16 „	From + 50° to + 4° = 46°
Sodium sulphate . 5 parts Sulphuric acid diluted . 4 „	From + 50° to + 3° = 47°
Sodium sulphate . 8 parts Hydrochloric acid . 9 „	From + 50° to 0° = 50°
Sodium nitrate . 3 parts Nitric acid diluted . 2 „	From + 50° to − 3° = 53°
Ammonium nitrate . 1 part Sodium carbonate . 1 „ Water . . . 1 „	From + 50° to − 7° = 57°
Sodium sulphate . 6 parts Ammonium chloride . 4 „ Potassium nitrate . 2 „ Nitric acid diluted . 4 „	From + 50° to − 10° = 60°
Sodium phosphate . 9 parts Nitric acid diluted . 4 „	From + 50° to − 12° = 62°
Sodium sulphate . 6 parts Ammonium nitrate . 5 „ Nitric acid diluted . 4 „	From + 50° to − 40° = 90°

(*see continuation on next page*)

TABLE 1.—(*continued*)

Freezing Mixtures.

Composition by weight.	*Reduction of Temperature in degrees Fahr.*
Snow or pounded ice . 2 parts Sodium chloride . . 1 „	To − 5°
Snow or pounded ice . 5 parts Sodium chloride . . 2 „ Ammonium chloride . 1 „	To − 12°
Snow or pounded ice . 24 parts Sodium chloride . . 10 „ Ammonium chloride . 5 „ Potassium nitrate . . 5 „	To − 18°
Snow or pounded ice . 12 parts Sodium chloride . . 5 „ Ammonium nitrate . . 5 „	To − 25°
Snow . . . . 3 parts Sulphuric acid diluted . 2 „	From + 32° to − 23° = 55°
Snow . . . . 8 parts Hydrochloric acid . . 5 „	From + 32° to − 27° = 59°
Snow . . . . 7 parts Nitric acid diluted . . 4 „	From + 32° to − 30° = 62°
Snow . . . . 4 parts Calcium chloride . . 5 „	From + 32° to − 40° = 72°
Snow . . . . 2 parts Calcium chloride crystalised 3 „	From + 32° to − 50° = 82°
Snow . . . . 3 parts Potash . . . . 4 „	From + 32° to − 51° = 83°

TABLE 2.

Evaporation of Liquids.

Liquid or Gas.		Water	Anhydrous Ammonia	Sulphuric Ether	Methylic Ether	Sulphur Dioxide	Pictet's Liquid
Specific Gravity of Vapour, compared with Air = 1·000		0·622	0·59	2·24	1·61	2·24	—
Boiling Point at atm. pressure		Fahr. 212°	Fahr. −37·3°	Fahr. 96°	Fahr. −10·5°	Fahr. 14°	Fahr. −2·2°
Latent Heat of vaporisation at atm. pressure		966	900	165	473	182	—
See Fig. 1, *Plate* 52.	Fahr.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
	−40°	—	—	—	—	—	—
	−20°	—	19·4	—	12·0	5·7	11·6
Absolute	0°	—	30·0	1·5	18·7	9·8	15·4
Vapour	+20°	—	47·7	2·6	28·1	16·9	22·0
Tensions	+32°	0·089	61·5	3·6	36·0	22·7	27·0
in	+40°	0·122	73·0	4·5	42·5	27·3	31·3
lbs.	+60°	0·254	108·0	7·2	61·0	41·4	44·0
per	+80°	0·503	152·4	10·9	86·1	60·2	60·0
square	100°	0·942	210·6	16·2	118·0	84·5	79·1
inch	120°	1·685	283·7	23·5	—	117·5	99·7
at	140°	2·879	—	33·5	—	—	—
different	160°	4·731	—	45·6	—	—	—
temperatures.	180°	7·511	—	62·0	—	—	—
	200°	11·526	—	81·8	—	—	—
	212°	14·7	—	96·0	—	—	—

Discussion.

Mr. LIGHTFOOT exhibited an excellent working model, made by Messrs. Siebe Gorman and Co., which represented one of the vertical cold-air machines shown in Figs. 22 and 23, Plate 61, and was about one-quarter full size, a chamber being attached for illustrating its action. The air was either drawn back from the chamber by the suction-pipe of the machine, in order to be used over again, or was allowed to escape direct into the atmosphere.

A late type of the Haslam dry-air refrigerator, shown in Figs. 12 and 13, Plate 56, really consisted of two complete refrigerating machines, placed side by side on one large bedplate, and capable of being worked either independently or together. When the whole apparatus was in operation, the steam was used expansively on the compound principle, expanding from the small into the large steam cylinder; but in case of accident either side might be worked alone, with high-pressure steam. If necessary the main shaft might be disconnected at the point X, Fig. 13.

Colonel B. H. MARTINDALE, C.B., R.E., said that, as the general manager of the London and St. Katharine Dock Company, he had been connected for the last five years with the practical working of arrangements for preserving refrigerated meat from the colonies on perhaps the largest scale that had ever been carried out in England. In 1881 the dock company were pressed by some of their Australian friends to make arrangements for receiving frozen meat and storing and distributing it. They began necessarily on a very small scale. Happening to have under one of their warehouses a large vault about 500 feet long, divided longitudinally into four arches each 16 feet wide, they made use of part of it for their storage. They began with a small engine obtained from Messrs. Hall of Dartford, delivering 10,000 cubic feet of cold air per hour; and that engine did good work until 1884, when it was removed to make room for a larger one. They gradually increased the number of their

cold storage chambers, until they had now got fifty-six chambers in two vaults. The smallest chamber had a cubic content of 2,273 feet, and the largest of 9,280 feet, the total content of the fifty-six chambers being something over 183,000 cubic feet. It was found that the carcasses averaged in weight 56, 60, and 72 lbs.; and if the chambers could be completely filled they would hold about 59,000 sheep of the first weight, 56,000 of the second, and 44,000 of the third. But in practice a space had to be left for gangways, and for separating different marks, especially in consignments from New Zealand; and a proportionate deduction had therefore to be made from what could otherwise be stored. Still the chambers could always store about 44,000 sheep, taking the shipments as they chanced to arrive.

The construction of the chambers had varied a little in detail, and was somewhat different from what had been described in the paper. The last chambers that had been built had been constructed according to the recommendation of Mr. Haslam of Derby. On the original concrete floor of the vault there was placed a longitudinal layer of $1\frac{1}{4}$-inch rough boards, on which were laid transverse bearers, $4\frac{1}{2}$ inches deep by 3 inches wide and 21 inches apart. On these bearers was laid a $2\frac{1}{2}$-inch batten floor, grooved and tongued. The sides and roof were constructed with $5\frac{1}{2} \times 3$-inch uprights, fixed on the floor bearers. On these uprights there was an outer skin of 2-inch boards; and an inner skin formed by two thicknesses of $1\frac{1}{4}$-inch boards, between which was a thickness of specially prepared brown paper. The $5\frac{1}{2}$-inch space between the inner and outer skins of the sides and roof, and the $4\frac{1}{2}$-inch space between the floor and rough boards, were filled with carefully dried wood-charcoal. All the boards were finished to a uniform thickness, and were grooved and tongued. Cold air was conveyed by wooden trunks from the refrigerating machines into the chambers, entering them at one end close to the roof, and being drawn off at the other end, also close to the roof, by return air-trunks leading back to the refrigerating machines. From the quantity of snow made by the engines, the air-trunks had to be cleared out every twenty-four hours, and the engine snow-boxes about every four hours. All sharp rises or falls

(Col. B. H. Martindale, C.B., R.E.)

in the air-trunks should be avoided by conducting the air through sloping trunks. In a properly insulated air-chamber, filled with frozen carcasses and kept closed, the temperature should not rise more than about 6° in twenty-four hours if the engines were stopped for that length of time. In order to make some use of the snow, which in any case was an exceedingly objectionable product, it was thrown into boxes fixed over a drain, and through these boxes passed the pipe conveying the circulating water.

At present they had four of Haslam's 60,000 cubic feet machines, and three of Hall's 30,000 cubic feet machines. These were supplied with steam from three multitubular boilers of the marine type, and four boilers of the locomotive type. If they started afresh, they would not have any boilers of the locomotive type; but they had had to feel their way step by step with the gradual growth of the trade.

At the stores at the A jetty, one of Haslam's 60,000 cubic feet machines was working at the present time on fifteen chambers, having a total capacity of 48,000 cubic feet, which were capable of storing 11,000 sheep of an average weight of 72 lbs.; but allowing for gangways and for divisions of marks, that number had to be reduced to 8,000 or 9,000. The engine was running twenty hours out of every twenty-four. The four hours' stoppage included the necessary time for clearing valves, snow-boxes, and air-trunks. The average speed was 80 revolutions per minute at an air-pressure of 44 lbs. per square inch, giving a temperature of −57° in the snow-boxes, and keeping the chambers down to a temperature of from 15° to 18° Fahr., which was found in practice to be about the best temperature to keep the meat at. It had been found that better results were obtained in proportion to fuel by working at an air-pressure of about 44 lbs. per square inch, instead of 50 lbs. and upwards: not giving such a low temperature in the snow-boxes, but about −50° Fahr. instead of −60° or −70°, and delivering a larger volume of cold air into the chambers; the proportionate rise in temperature was then much less between the delivery from the expansion cylinder and the distant chambers. At the same jetty were two of Hall's 30,000 cubic feet machines, working on fifteen chambers of about the same capacity,

and doing just about the same work. The coal used in the twenty hours was about 4½ tons for the three machines together.

At the B jetty, two of Haslam's 60,000 cubic feet machines were working on twenty-four chambers of 90,000 cubic feet capacity, running at an average of 70 revolutions per minute with an air-pressure of 40 lbs. per square inch, a temperature of −55° in the snow-box, and a coal consumption of 4½ tons in the twenty hours. That was much the same result as with the 60,000 and the two 30,000 cubic feet machines at the A jetty.

The rise of temperature in the air in travelling to the chambers at any distance was generally considerable. As a rule the chamber next to the engine was kept at a sufficiently low temperature with but little opening of the delivery ports in the air-trunks, and almost without admitting air at all; the mere passage of the air-trunks through it kept it almost cool enough. The greatest care had to be taken in regulating the delivery and return air-ports, gradually increasing the area of both in proportion to the increased distance. The greatest distance that the air was conveyed was 180 feet. The practical result of the observations taken, extending over some time, was that the rise of temperature in travelling was 1° Fahr. for every 18 or 20 feet travelled; but this must not be taken for more than the result arrived at from general working under existing conditions.

The consumption of 4½ tons of coal in twenty hours for the three engines at the A jetty together, giving out nominally 120,000 cubic feet of air per hour, was equivalent to 1 lb. of coal for every 240 cubic feet of cold air delivered. The coal used was ordinary Welsh coal at about 16*s.* 6*d.* per ton.

It had also been found that from 1 to 1½ cubic foot of cold air per hour would keep cool—say at 18° Fahr.—1 cubic foot of storage at a distance not exceeding 180 feet, or say at an average distance of 90 feet. The result which he had first arrived at had been that in temperate weather 1 cubic foot of cold air per hour was sufficient to keep cool 1 cubic foot of storage. Some considerable time after he had arrived at that conclusion he mentioned it to Mr. Haslam, and to his pleasure found that he also had arrived at the same

(Col. B. H. Martindale, C.B., R.E.)

conclusion. But allowance had to be made for openings of doors for the purpose of deliveries and so on; and on this account he thought the quantity of air required could not be put at much under $1\frac{1}{2}$ cubic foot per hour for every cubic foot of storage that was wished to be kept down to say 18° Fahr. Of course if the chambers were to remain undisturbed and fully stored with carcasses, one cubic foot of cold air for every foot of storage would probably be found sufficient.

One precaution to be observed in connection with all apparatus employed for refrigerating meat was that, if chemicals were used in producing the cold, it was an absolute necessity that the air delivered should not have the faintest trace or smell of them. No consignee would keep his meat in any store where he could detect the slightest taint of that kind.

Mr. FREDERICK COLYER, regretting that he was prevented by illness from being present, sent the following remarks upon the paper, which were read by direction of the President:—

"The paper forms a valuable contribution to the Proceedings, especially as the author has had so much experience in this class of machinery.

"On page 211 Harrison's ether machine is mentioned as being the first ice-making machine that came into practical use in this country. It may be of interest to state that one of the first of Harrison's machines made on this system is still at work at Messrs. Truman Hanbury and Co.'s brewery, and is acting very efficiently; it has been there I believe about thirty years.

"On page 212, where the quantity of cooling water used in the condenser is given as 150 gallons per hour for each ton of ice made per twenty-four hours, I should like to know the temperature of the water at the inlet of the condenser, as this makes a material difference.

"On pages 215 and 230 the consumption of coal per indicated horse-power is taken at 2 lbs. per hour. This I think is too low an estimate, and that 3 to 4 lbs. would be nearer. The price of coal also, which is taken by the author at 15*s.* per ton, is too low, at any

rate in the London district; it should be 18*s.* to 20*s.* These corrections would raise the cost per ton for producing block ice.

"On page 231 English beer is spoken of as not being cooled below 50° Fahr. This is really much lower than is usually the case; 60° would be nearer as a rule.

"On page 232, I quite agree with the author that cold-air machines would be the most suitable for cooling rooms for fermenting and other purposes; but the cost of fuel stands in the way at present.

"Machines for cooling water and making ice may be divided into two classes:—one in which ether is used, and the other in which ammonia is the medium. The other systems mentioned in the paper are seldom employed in this country.

"With ether machines there are advantages which in some instances may decide their use when space is limited or when the machine has to be placed in underground rooms; those made upon the horizontal plan can often be adopted where it would be almost impossible to use the ammonia machine.

"In London, where coal is dear and water has often to be obtained from the water companies, the ether system is more expensive than the ammonia; added to which a much larger quantity of condensing water is required; and, taking into consideration the high temperature the water often attains in the street mains during summer, the increased quantity used by the ether machine is a serious matter.

"The ammonia machines—whether those described on page 219, such as the Pontifex-Reece system, or those worked on the compressed plan—are as a rule far more economical in working than any ether machine. They should however be adopted only where the plant can be partly open to the air; it is almost impossible to prevent a slight leakage, which in many instances would preclude their use, as the vapour given off would be injurious to other processes carried on at many establishments.

"Having tested the working of some of the leading ether machines, and also of the Pontifex-Reece ammonia machine, I have obtained the following results, which may be of interest.

(Mr. Frederick Colyer.)

"In an ether machine made by Messrs. Siebe Gorman and Co., capable of cooling 3,200 gallons of water from 60° down to 50° or abstracting 320,000 heat-units per hour, the average of experiments gave 4,250 gallons per hour cooled 10° Fahr. The temperature of the water at the inlet was 54°, and that of the water used for condensing purposes was the same. The maximum cooling effected was 449,437 heat-units abstracted per hour, being from 35 to 40 per cent. above the nominal power of the machine. The condensing water used per hour was 1,262 gallons, or about 3-10ths of a gallon for every gallon of water cooled. The coal consumed was $3\frac{1}{4}$ cwts. per hour; it was of indifferent quality, or the consumption would have been smaller. The steam cylinder was 21 ins. diameter and 27 ins. stroke; the air-pump 24 ins. diameter and 27 ins. stroke. The speed of the engine was 58 revs. per minute, with 48 lbs. steam cut off at one-third of the stroke. The indicated power of the engine was 53 HP., and of the air-pump 29·2 HP. The boiler was 7 ft. diameter and 24 ft. long, and gave an ample supply of steam. This is the most efficient ether machine that has come under my notice, and contains several improvements not usually found in others of the same class.

"In a Pontifex-Reece ammonia machine, capable of cooling 5,500 gallons of water per hour through 10° Fahr., 6,388 gallons per hour were actually cooled 10°, being about 16 per cent. above the nominal power. The condensing water used per hour was 1,320 gallons at $45\frac{1}{2}$°. The fuel consumption in twenty-four hours was $21\frac{1}{2}$ cwts. of the very common coal in the Glasgow district, or 100 lbs. per hour. The steam pressure was 50 lbs. per square inch; the boiler was 6 ft. diameter and 20 ft. long.

"The same Pontifex-Reece ammonia machine when employed for making ice is capable of producing 15 tons in twenty-four hours if worked with three boxes, or 10 tons with two boxes. In the experiment two boxes only were used. The coal consumption was $25\frac{1}{4}$ cwts. in twenty-four hours, or 120 lbs. per hour, or 192 lbs. of coal per ton of ice. Including all expenses, wear and tear, interest and sinking fund, the cost of the ice was 4*s*. per ton. The condensing water used, having a temperature of 46° at the inlet, was 1,154

gallons per hour; and 1,340 gallons in full working with three boxes. The engine was 6 HP. nominal. The boiler pressure was 43 lbs. per square inch, and the boiler used was the same as in the cooling experiment.

"In ammonia machines worked upon the compressed system the difficulty has hitherto been to keep the working parts tight at the joints. I believe Messrs. Siebe Gorman and Co. are about to bring out a machine that will be free from this difficulty. From my own experience with cooling and ice-making machines I am led to think that the ammonia system will shortly be the only one used upon any extensive scale.

"As to the amount of ice produced per ton of coal in Pictet's process, mentioned in page 223 of the paper, I think it is overstated at 35 tons. Half that production would still be very high.

"With cold-air machines the author has had as much experience as any one, and I have therefore been hoping to learn what he could do towards producing a machine capable of cooling air economically in a large room, not a sealed chamber. In breweries and other places, such a machine would be a great boon; hitherto the machines tried have been little more than costly failures. The difficulties are very great, it is true; but much has been done by the author in this direction, and I am looking forward to a successful solution of the problem. No other machine than his I think would be of any practical service for this purpose. The cost, as well as want of efficiency, has always stood in the way of the practical use of cold-air machines for cooling large rooms."

Mr. W. A. GORMAN mentioned that the other machine, referred to by Mr. Colyer as still at work at Messrs. Truman's brewery, had been made by the late Mr. Siebe, and was the first machine made on Mr. Harrison's plan except the one taken by himself to Australia. For a small production of from 2 cwts. up to 3 tons of ice per day, the other machine was much liked on account of the low working pressure in the condenser, not exceeding 10 lbs. per square inch even in India. In one instance a half-ton machine of this kind was driven in conjunction with dynamo machines by water power.

(Mr. W. A. Gorman.)

The working model exhibited of a vertical cold-air machine he should have had much pleasure in presenting to the Institution, if they had had a suitable place in which to keep such models, as he hoped would at some future time be the case.

Mr. JAMES HARRISON drew attention to the figures given for the latent heat of vaporisation in Table 2, where that of ammonia was set down at 900 and that of sulphuric ether at 165. No doubt these were the correct figures for equal weights of the substances at atmospheric pressure. But the ice-maker, using pumps which were measures not of weight but of capacity, did not deal with vapours by weight but by volume; and did not work at atmospheric pressure. At pressures below the atmosphere the latent heat of vaporisation was increased, and at pressures above the atmosphere it was diminished. On making these corrections it would be found that at 32° Fahr., and with a vacuum of 11·1 lbs. per square inch below the atmosphere, the latent heat of ether in the ice-making process was 656 instead of 165; and in working with ammonia at 32°, and at a pressure of 46·8 lbs. above the atmosphere, its latent heat was reduced from 900 down to 845. Other considerations connected with the temperature of condensation of the vapours of ammonia and ether led him to the conclusion that these two refrigerating agents were nearly equal in efficiency. Indeed it was his opinion that of all the different refrigerating agents of this class there was no one really better than another, but that all were about equal; and that if in any process one seemed to be more efficient than another, it was simply because the arrangements for its use had been better carried out in respect of that process. It so happened that in his first Australian design he had planned a process of ice-making by ammonia, which combined both the compression and the absorption processes before either of these had been invented separately. But he had not proceeded with the use of ammonia as a refrigerator, having subsequently given the preference to ether.

Mr. R. PRICE-WILLIAMS should have been very glad of more particulars as to the cost of different processes per ton of ice made, which

according to the paper appeared to vary from 9*s*. 3*d*. on page 204 to 3*s*. 9*d*. on page 218, while it was stated on page 221 that the average cost by the absorption system might be taken at 4*s*. In a recent voyage to Australia he had had an opportunity of examining very carefully the refrigerating process referred to in page 235 as having been carried out by Mr. Manuel, and could bear willing testimony to the admirable way in which it served its purpose. In Australia the use of refrigerating machinery for the preservation of meat was already becoming a subject of great importance; and there was no disguising the fact that in this country it was a very important one indeed. So much so that Sir William Armstrong, in a letter to himself, dealing with the very rapid increase of population in this country, admitted it to be one of the gravest questions of the day; and pointed out very forcibly what a terrible thing it would be for this country if it should ever happen that the freedom of navigation should be destroyed, considering that we were absolutely dependent upon food supplies from abroad. By means of this refrigerating process, any amount of food that could be taken by this country could now be sent over from Australia. But he had been given to understand that a mistake had been made in freezing the meat for transport, and that the arrangements must be such that the meat should not be absolutely frozen, but should be kept down as near the freezing point as possible. Mr. Manuel's arrangement he had noticed was so contrived that nothing was actually frozen; and the butter and meat were as fresh at the time of arriving at King George Sound in Western Australia as on the day of leaving England. The valuable information afforded by Colonel Martindale's remarks was not only highly interesting to those who had listened to them, but would also be of very great interest on the other side of the world.

In connection with the successful application of the refrigerating process on board ships, it had struck him that it might be equally and with very great advantage applied to the berths, in which, under the heat of the tropics and with port-holes closed for many days, a temperature above 100° Fahr. had to be endured. From an estimate made during the voyage in the Massilia, he came to the conclusion that by the expenditure of the small sum of £700 on board that fine

(Mr. R. Price-Williams.)

vessel the berths might be maintained at a constant temperature of from 60° to 70° Fahr. if desired. The adoption of this suggestion by the Peninsular and Oriental Company would add very largely to the comfort of their passengers, and he believed would induce people to make journeys to the torrid zone much more frequently.

Great credit he thought was due to the author for the admirable way in which he had placed this subject before the Institution. It was evident that he had devoted a large amount of time to it, and had made it his special study.

In regard to the very interesting means of arresting the running ground for putting the Stockholm tunnel in, he enquired whether the setting of the mortar was not interfered with; because it was well known that if brickwork were laid during frost it was apt to blow, and masons never set brickwork, or anything with mortar, during frost if they could avoid it. He should have feared the freezing of the ground in the manner described in the paper would have very much interfered with the proper setting of the mortar.

Mr. DRUITT HALPIN observed it was pointed out in page 233 of the paper that, when once the chamber and its contents were cooled down to the required temperature, all that the refrigerating machine had then to do was to overcome the leakage of heat passing in through the walls. If that could be prevented, of course theoretically the machine could be stopped altogether. The importance of the insulation was therefore very great, because a large amount of power and coal was being used to neutralise the leakage. The best non-conductor of heat, as was well known, was air; and the more air was entangled, the more efficient it became. In Germany he had lately made some experiments, extending over a week, with cork as a non-conductor, according to a plan now in use there. In France cork had been used many years before, and had been employed in the 1878 Exhibition, where it answered efficiently for protecting steam pipes; but the objection in the French arrangement, as far as he understood, was the expense. Ordinary cork was cut up into slices, and a good effect was thereby obtained, but at very great expense. In Germany however all the refuse and waste cork was used; it was ground up

into powder, and was then cemented together again, and made an exceedingly cheap non-conducting material. The broad results of his own tests with this cork were that from 92 to 93 per cent. of the transfer of heat was totally arrested, and only 7 or 8 per cent. of heat passed through.

Mr. William Schönheyder remarked that in the tunnel at Stockholm it appeared the cold air had simply been delivered by means of a shoot into the working chamber, and there allowed to take care of itself. Of course it picked up heat from the surrounding ground, and the warmer air would rise to the ceiling, and there stop, unless it were taken away. If a higher temperature were really wanted near the ceiling, so much the better; but if it were wanted to have the air cold near the ceiling, the plan would have been either to withdraw the air from the ceiling by means of a powerful pump, or simply to insert a curved tube from the outside, terminating near the ceiling, so that, while the cold air was blown into the chamber by the machine, the warmer air might be continually taken away from near the top by the tube. In the cold storage arrangement shown in Fig. 26, Plate 62, the cold air was admitted near the ceiling and the warm air was taken away from near the ceiling. Perhaps that did not matter very much, because directly the cold air came in it would fall to the floor, and as it picked up heat from the surrounding walls, it would rise and go out at the top; so far that was right enough. But if with these cold-air machines there was any chance of snow getting in with the air and collecting in the chambers, it seemed to him that in this arrangement where it was admitted near the ceiling it had a great opportunity of falling upon the meat, and possibly deteriorating it. The air might just as well be admitted near the floor, which was the proper place for it to enter at. It would then gradually rise as it picked up heat from the chamber and its contents; and it should be taken away from near the ceiling, as was already done.

Mr. Thomas Powell, Rouen, being unable to come to the Meeting and take part in the discussion, sent the following observations

(Mr. Thomas Powell.)

resulting from his own experience with Windhausen's vacuum plan:—

"The importance of refrigerating and ice-making machinery is constantly increasing, and the artificial production of cold is becoming more and more extensively useful in various manufactures. Being myself engaged in the manufacture for France and her colonies of vacuum machines on Windhausen's plan, which in England has been but little used, I am able to offer some supplementary information regarding it, beyond that given in the paper. The remarks there made would fairly have applied to this plan two years ago; but since then improvements have been made, whereby all the objections that attended it have been thoroughly met.

"The first of these improvements has reference to the quality of the ice. Instead of the water to be frozen being subjected direct to the vacuum itself, the vacuum is made to act upon a liquid that will not freeze at the lowest temperature employed in the apparatus. A solution is used of chloride of sodium or magnesium or calcium, which in its partial vaporisation loses heat enough to bring its temperature down to 14° or even to zero Fahr. (10° or 18° below zero Cent.). Under the action of a pump, the cold liquid circulates continuously between the evaporator or refrigerator in which the cold is produced, and the apparatus or place where the cold is to be utilised. It is thus both the means by which the cold is produced, and also the carrier by which it is transmitted. It can be conveyed either into tubular coolers, such as are used in breweries, or into any other apparatus where the cold is wanted to be utilised; and in ice-making apparatus the ice thereby produced is either opaque or transparent according to the nature of the apparatus employed, just as in the case of all other plans for making ice. By means of the processes already known, the ice can on this plan be made perfectly transparent, and in blocks of any forms and sizes. In my own works I am at present trying a very simple apparatus for producing transparent ice without stirring the water at all, and without using distilled water. The method consists simply in gradually increasing the coldness of the liquid used for freezing the water.

"Another improvement made more than a year ago in our machines consists in causing the sulphuric acid to circulate continuously under the action of a pump between the absorber, in which it becomes diluted through the work that it does there, and the concentrator, in which it is regenerated. Formerly work had to be stopped every six or seven hours for an hour at least, in order that the weak acid in the absorber might be replaced by a fresh charge of strong acid. By the improved arrangement the machine can now work continuously without interruption, except for such attention as all running machinery requires. An increased production is thus obtained of at least 15 per cent., accompanied by a decided saving in power, inasmuch as it is from the moment of starting the vacuum pump until the full amount of vacuum is produced, that the greatest power is required.

"Another consequence resulting from the continuous circulation of the acid is that the machine works much more regularly, the production of cold is uniform, and risk of damage in the various parts of the apparatus, particularly in the concentrator, is almost entirely got rid of. The concentrator itself, which in the old machines was certainly deficient in strength and has undoubtedly been the cause of this plan not having come more into use, has been entirely altered, or replaced by various other modes of construction, which have all of them given very satisfactory results. One of these new concentrators, designed in London, is now under trial. An entirely different one has already undergone a number of trials in Berlin; and a third is employed in my works, where it is giving complete satisfaction.

"In regard to cost of working, the production of cold by vacuum with the aid of sulphuric acid shares with ammonia absorption the advantage rightly pointed out in the paper, namely that in these two plans the heat necessary for performing the work is for the most part applied direct, without being transformed into mechanical power. In our system the heat is employed in regenerating the acid by concentration; the power expended in driving the vacuum pump forms only a small portion of the total work.

(Mr. Thomas Powell.)

"Although not for the production of cold, another application of this plan of machine may be mentioned, which is nevertheless of high importance, namely for evaporating and drying in a vacuum and at a low temperature: — for instance, evaporating the syrups of sugar and starch; concentrating fruit syrups for preserving, without their being at all injured by heat; concentrating grape-must for carriage, and preserving it without fermentation; condensing milk; thoroughly drying meat and glue, &c. The plan is suitable in fact for all kinds of substances, which in the ordinary process of concentration by heat and under atmospheric pressure suffer more or less deterioration. By this means milk can be frozen solid without reducing its temperature lower than 4° below zero Fahr. (20° below zero Cent.), and consequently without coagulating the albumen; this is done by simply putting the vessel containing the milk into communication with the vacuum apparatus. The importance of such a result can hardly fail to be appreciated."

Mr. LIGHTFOOT, in reply, observed that Colonel Martindale had furnished a large mass of information in regard to the working of cold-air machinery and storage chambers, which if accurate would be extremely useful. He had no particular reason for doubting its accuracy, as far as the dock company was concerned; but he had found in many instances that refrigerating machines, sold to give a certain delivery of cold air per hour, fell far short of that delivery in practice; therefore, unless the capacities were arrived at from the actual sizes of the cylinders and conditions of working, he feared it would be unsafe to draw any deductions, or to make comparisons between the volume of air delivered and the space cooled. Not very long ago a case had come under his notice in which the capacity of the machine, stated as so many thousand cubic feet of cold air per hour, had actually been calculated from the capacity of the compressor, a method which gave a delivery nearly double of that obtained in practice.

That there was something wrong in the figures seemed to be shown by the coal consumption, which was given as $4\frac{1}{2}$ tons per twenty hours for three machines stated as delivering collectively

120,000 cubic feet of cold air per hour. As at least 220 indicated horse-power would be required to give this production of air, the coal consumption was equivalent to $2\frac{1}{4}$ lbs. per indicated horse-power per hour, a result which he considered could not possibly be obtained with the not very efficient boilers and engines in use at the docks, the engines being of a type that would entail a fuel consumption at least one and a half times as much as that required to develop the same result in his horizontal machine with compound condensing engine, as shown in Figs. 17 and 18, Plates 58 and 59. He therefore felt quite sure that, if the coal consumption had been correctly given, the air delivery could not be taken at anything like 120,000 cubic feet per hour; and if this was so, the whole of the calculations and deductions therefrom were upset.

With regard to Mr. Colyer's remarks, the water consumption for the ether machine was merely given as a general guide, the amounts actually used varying too much to permit of any accurate statement being made. The consumption and price of coal were not put forward as being the actual figures in any particular case, but had been assumed as a basis of calculation common to all the machines; they would therefore have to be altered according to circumstances. At the same time the most improved class of cooling and ice-making machinery was now made with engines developing one indicated horse-power with about 2 lbs. of coal per hour. He could not understand why the ether machine could be used in situations where an ammonia machine could not be got in. If an ammonia absorption apparatus was referred to, it might be true; but an ammonia compression machine occupied less space than any machine with which he was aquainted. He had not stated as a definite fact that Pictet's new process produced 35 tons of ice per ton of coal; but there was nothing impossible in such a result. Probably actual figures would be made known before long, and it would then be time enough to come to a definite conclusion. He was afraid he could hold out no hope that cold-air machines would ever be capable of being economically applied for cooling air in large rooms, such as were to be found in breweries; nor indeed did he see why such an application was to be desired, as there was no difficulty whatever in

(Mr. Lightfoot.)
cooling by means of brine from an ammonia or other machine—a system that had been very extensively adopted, and found to work well.

It had been correctly pointed out by Mr. Harrison that the heat of vaporisation varied with the pressure at which evaporation occurred; this was well known, and had been referred to in the paper. Unfortunately the latent heats of vaporisation at different pressures had never been determined for the liquids used by the ice-maker, except in the case of water; and therefore all that could be done was to give those at ordinary atmospheric pressure. In determining the proper size of pump to produce any given effect, it was necessary to take into account the specific gravity of the vapour as well as the heat of vaporisation at the particular pressure at which it was intended to work the apparatus.

The cost of ice-making had been estimated upon the same bases for all the different machines; and he was afraid he could not furnish more detailed information, as suggested by Mr. Price-Williams. In point of fact each particular case required special consideration; and all that could be attempted in a paper such as the present was to give general results with machines of the same capacity and worked under similar conditions, which might be used for comparing the efficiencies of the various systems. Other matters however, besides mechanical and thermal efficiencies, had frequently to be considered. In reference to the question of freezing the meat brought over to this country, he believed it was essential that it should be frozen if it was to be preserved for more than from two to three weeks; for even if the temperature was maintained as low as 35° Fahr., a slow process of decomposition or a slow chemical change would take place, which if continued beyond that time rendered the meat tasteless, and otherwise lowered its quality. On the other hand he believed that no chemical change took place when the meat was frozen. There was a slight mechanical change, and the cellular tissue was to some extent destroyed; consequently when thawed there was a tendency for the juices to escape. This however was got over by hanging the carcasses and joints so that the juices were retained. His experience was that on board the Peninsular and

Oriental Company's steamers the meat was frozen; the length of voyage necessitated it.

No trouble had arisen from a deposit of snow upon the meat. As a matter of fact with his machines snow never got into the storage chamber; but if it did, no harm would ensue, so long as the meat was frozen. Various means had been tried for admitting the cold air; but the general practice now was to let it in by means of a duct near the ceiling, and draw it away by another duct also at the ceiling, but removed as far as possible from the inlet.

No difficulty had been experienced in setting the cement in the Stockholm tunnel. The arch was constructed after the partition forming the freezing chamber was removed; and although the gravel next the cement was frozen, no ill effects had been felt. In regard to the method of applying the cold air in the freezing chamber, it must be borne in mind that, as mentioned in the paper, it had been considered advantageous that the gravel at the top of the tunnel should not be frozen. Had it been desirable to freeze at this part, means would have been devised for doing so.

Respecting the use of cork as a non-conductor, he should be glad of some particulars as to the experiments referred to by Mr. Halpin, because the mere statement of the percentage of heat passing through was hardly sufficient. These matters were generally dealt with by stating the transmission of heat in thermal units through one inch thickness of the material, per square foot, per hour, per degree of difference in temperature; and if the results with cork could be given in that form, it would be an advantage. The question of insulation was a very important one, and he had himself experimented with most of the substances generally used. In several cases he had employed silicate cotton, which for some purposes was better than almost anything else. But charcoal he believed was the best insulator for general use.

He could not consider that all the objections to the Windhausen vacuum process had been met by Mr. Powell. No doubt improvements had been effected since the machine was erected at Lillie Road, the principal change being in the elimination of defects in the concentrator, and in rendering the working of the plant continuous.

(Mr. Lightfoot.)

The method of producing clear ice had already been referred to in the paper, and was well known to those acquainted with ice-making plant. It could only however be taken as an improvement, in so far as it enabled clear ice to be made: against which would have to be set an increase in the amount of fuel consumed per ton of ice, as well as an increase in cost of labour. The vacuum process he feared could never compete with ammonia as regarded cost of production, while there could be no doubt that the plant was more costly to maintain and manage.

Mr. W. SILVER HALL suggested that the question about the setting of the brickwork in the Stockholm tunnel was almost answered by the diagram itself, Fig. 32, Plate 63, which showed that the brickwork was put in outside the freezing chamber.

The PRESIDENT asked the members to pass a hearty vote of thanks to Mr. Lightfoot for his very interesting and instructive paper; and he thought they might fairly include in the vote of thanks those who had contributed to the discussion, especially Colonel Martindale, Mr. Colyer, and Mr. Powell, who had given very valuable information on the subject dealt with.

MEMOIRS.

William Fothergill Batho was born at Salford on 11th January 1828. After serving an apprenticeship with his father, an engineer and toolmaker in Manchester, he became an assistant on the East Lancashire Railway. In 1846 he entered the drawing office of Messrs. Sharp Brothers and Co., Manchester, and subsequently went to Natal as a government surveyor. On returning to England he was again engaged at Messrs. Sharp's, where he worked out the detail of the double-traversing drilling and grooving machine described in the Institution Proceedings 1856, page 111. Subsequently he was with Messrs. Beyer Peacock and Co.; and from 1858 to 1862 he was in business on his own account. He then became manager of Messrs. Peyton and Peyton's tube works, Birmingham; and from 1866 to 1870 was manager of Messrs. Nettlefold and Co.'s screw works, Birmingham, where he devised a nut-shaping machine of which he gave a description to this Institution (Proceedings 1869, page 312). Throughout this period he also practised as a consulting engineer, and in connection with the late Mr. William Clark devised a steam road-roller, of which he gave a description to the Institution (Proceedings 1870, page 109), and superintended the construction of drainage pumping engines and water-works engines for the municipality of Calcutta. Subsequently he became managing partner of Sir Josiah Mason's steel-pen works in Birmingham, until 1871, when he established himself in London as a civil and consulting engineer. In this capacity he acted as engineering adviser and agent for the municipality of Calcutta and for the Calcutta Port Trust, besides being regularly consulted by the India Office. In conjunction with the late Mr. William Clark he acted as consulting engineer to the Oude and Rohilkund Railway, and continued in that capacity after the death of Mr. Clark; and with Mr. Wm. Duff Bruce, vice-chairman of the Calcutta Port Trust, he

introduced the hydraulic dredger known by their joint names, which has met with an extended and very successful application. More recently his name has become widely known in connection with the Batho open-hearth steel-making furnace, which is now in successful operation in many of the works both in this country and on the continent. After a lengthened illness he died at Bournemouth on 16th May 1886, at the age of fifty-eight. He became a Member of this Institution in 1860.

JOHN TOWLERTON LEATHER was born at Kirkham Gate, near Wakefield, on 30th August 1804, being the eldest son of Mr. James Leather, colliery proprietor, of Beeston Park, near Leeds. He was articled to his uncle, Mr. George Leather, engineer of the Aire and Calder Navigation, Goole Docks, and other works; and in 1829 commenced practice as an engineer in Sheffield. In 1833 he was appointed engineer of the Sheffield Water Works, for which he carried out the construction of reservoirs at Redmire's and Crooke's Moore near Sheffield. In 1839 he commenced business as a contractor in partnership with Mr. Waring, their first joint undertaking being a portion of the Midland Railway at Chesterfield. They subsequently constructed the Chester and Crewe section of the London and North Western Railway. After dissolution of partnership, Mr. Leather undertook on his own account the Tadcaster and York Railway; and from 1847 to 1850 he constructed the Erewash Valley line of the Midland Railway. In 1849 he was entrusted with the construction of the Portland Breakwater. In 1854 and 1855 he was engaged in carrying out the River Nene improvement works between Wisbech and Peterborough; and about the same time he successfully put in the foundations of the Suspension Bridge at Inverness. In 1861 he was engaged by the War Office to construct the foundations of the Sea Forts at Spithead, and afterwards also their superstructures, besides building the Gilkicker and St. Helen Forts. In 1862, on the occasion of the failure of the St. Germains' sluice of the Middle Level drainage, and the consequent disastrous inundation from the river Ouse, he carried out the construction of the necessary dam and siphons. In 1867, in

association with the late Mr. George Smith, he entered upon the work of extending Portsmouth Dockyard. On the completion of this contract, about 1877, he retired from active business life and occupied himself with local affairs. He was a magistrate and Deputy-Lieutenant of Northumberland, and High Sheriff in 1875. His death took place at Leventhorpe Hall, near Leeds, on 6th June 1885, in his eighty-first year. He became an Associate of this Institution in 1859.

David Scott was born near Cupar, Fifeshire, on 12th March 1838, and having been educated at the Madras College, St. Andrews, was articled in 1854 at the iron works of Messrs. Balfour and Co., near Leven, Fifeshire. After serving his time for five years in these works, he returned in 1859 to St. Andrews, and studied there for an appointment in the Public Works Department of India, which he obtained in 1860. On arriving in India, he studied at the Civil Engineering College at Roorkee till July 1861, when he was appointed a second grade assistant engineer on the permanent staff of the Public Works Department in Oudh, and was employed on the construction of the trunk road between Lucknow and Fyzabad, and upon the large bridge over the Kallianee river. In 1866 he was promoted to be fourth grade executive engineer in charge of the station of Seetapore, where he remained till 1870, when he was appointed an executive engineer in the irrigation department, and employed on the surveys and plans for the Sardah Canal, Oudh, until the abandonment of the scheme in 1871. He was then appointed assistant secretary to the Government of India in the buildings and road branch. On returning from a visit to Europe in 1875, he was appointed, during the absence of the vice-chairman and engineer to the Port Commission of Calcutta, to conduct the duties of that office. Subsequently he rejoined the Public Works Department as an executive engineer in various parts of Bengal, and in 1877 had charge of famine relief-works in the Madras presidency. From May 1881 he again officiated as engineer to the Port Commission, Calcutta, till May 1883, when he had to take furlough for health. On his return he was appointed superintending engineer for wet docks at

Kidderpore. In June 1885 illness led him to make a voyage to Melbourne, where he landed on 5th July, and grew gradually worse till he died there on 29th August at the age of forty-seven. He became a Member of this Institution in 1876.

JOHN ROBSON WARHAM was born on 20th November 1820 at Newcastle-on-Tyne, where he served an apprenticeship in the celebrated engine works of Messrs. R. and W. Hawthorn. When about twenty-two years old he went to Burton-on-Trent as manager of the ironworks of the late Mr. Robert Thornewill, in which he became a partner in 1849. He continued a member of the firm of Thornewill and Warham to his death, which took place from bronchitis on 26th March 1886, in his sixty-sixth year. Besides being concerned, in his business relations, in the carrying out of numerous important colliery, brewery, and water works, he also took an active and leading part in many matters of public interest in his locality. He became a Member of this Institution in 1852.

EDWARD WILLIAMS was born at Merthyr Tydfil, Glamorganshire, on 10th February 1826, being the son of Mr. Taliesin Williams of that town, and grandson of Edward Williams—Iolo Morganwg—the celebrated Welsh antiquarian and poet. He received his education in his father's school, and was for some time an assistant there. In 1842 he entered the service of the Dowlais Iron Company, and after filling various positions at Dowlais and Cardiff became the manager of their extensive forges and mills. When Sir Henry—then Mr. Bessemer—read his paper before the British Association at Cheltenham in 1856, Mr. Williams seeing the report in the *Times* built within three or four days an experimental furnace for trying the process at Dowlais, which resulted in such success that the metal produced was rolled into a bar, of which a portion is now preserved in the office of the Iron and Steel Institute. He also rolled, and with his own hands stamped, the first Bessemer steel rails ever manufactured. In 1864 he left Dowlais to manage the house of Messrs. Guest and Co. in London; and in the succeeding year he accepted the position of general manager of the new firm of Messrs.

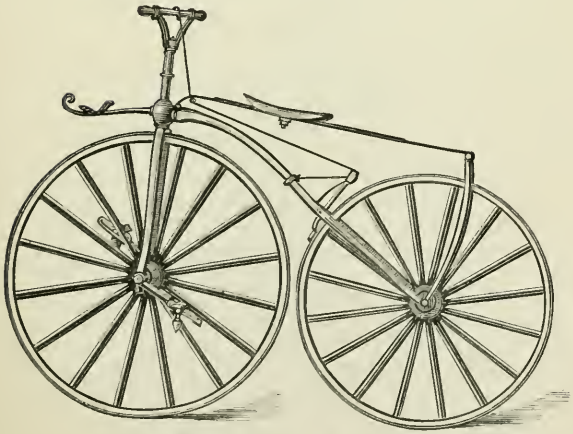
Bolckow Vaughan and Co., Middlesbrough, with whom he remained for ten and a half years; their great prosperity during that period is the best evidence of the energy and skill with which he conducted their affairs. He almost entirely remodeled their various works, pulling down the small old-fashioned blast-furnaces, and erecting in their stead the tall and more economical ones now generally in use. He also for the first time made use of the waste heat from the coke ovens for raising steam and drying bricks on the flats at Byers Green Colliery. In 1875 he entered into business as an adviser in matters relating to iron and steel works, and acted as consulting manager to the Rosedale and Ferryhill Company and to the West Cumberland Iron and Steel Company. In 1879 he purchased the Linthorpe Iron Works, Middlesbrough, which he carried on until his death. He designed and superintended the erection of the new steel works at Cyfarthfa for Messrs. Crawshay Brothers (see Proceedings 1884 page 380); in arrangement and suitability for economical working these works are believed to be as good as any in this or any other country. To questions of economy in the working of iron and steel he always gave great attention, and was one of the first to advocate taking iron in a fluid state from the blast-furnaces to the Bessemer converters. He became a Member of this Institution in 1865, and was an original member of the Iron and Steel Institute, having been chairman of the meeting held at Newcastle-on-Tyne for the purpose of establishing the Institute, of which he was a member of council from the first, and President from 1879 to 1881; and at the meeting in London this year the Bessemer gold medal was presented to him in recognition of his valuable services to the iron and steel trades. He was a member of the Institution of Civil Engineers, and a founder and Past-President of the South Wales Institute of Engineers. His death took place at his residence, Cleveland Lodge, Middlesbrough, on 9th June 1886, at the age of sixty, after an illness extending over many months.

Arthur Wellesley Westmacott Willmott, son of Alfred Willmott, M.D., Weston-super-Mare, was born at Chester on 18th November 1852, and died at Shanghai on 23rd February 1886, at the

age of thirty-three. After being educated at Fullands School, Taunton, he was apprenticed to the firm of Sir W. G. Armstrong and Co., Elswick, Newcastle-upon-Tyne; and after serving his term, he was admitted to the drawing office, obtained the gold medal of the Science and Art Department for applied science, and was subsequently engaged upon the erection of machinery. He then entered the service of the Chilian Government, to superintend the erection of work at Valparaiso. He afterwards re-entered the service of the Elswick firm; and at the end of 1884 was appointed manager to the gun factory at Kiangnan, Shanghai. He became a Member of this Institution in 1883; and in the summer of that year acted as Honorary Local Secretary at Antwerp for the visit of the Members attending the Belgian Meeting.

Fig. 1. "*Hobby Horse.*"

Fig. 2. "*Bone-shaker.*" 1869.



(*Proceedings Inst. M.E.* 1886.)

Fig. 3. "*Rudge*" *Roadster Bicycle.*

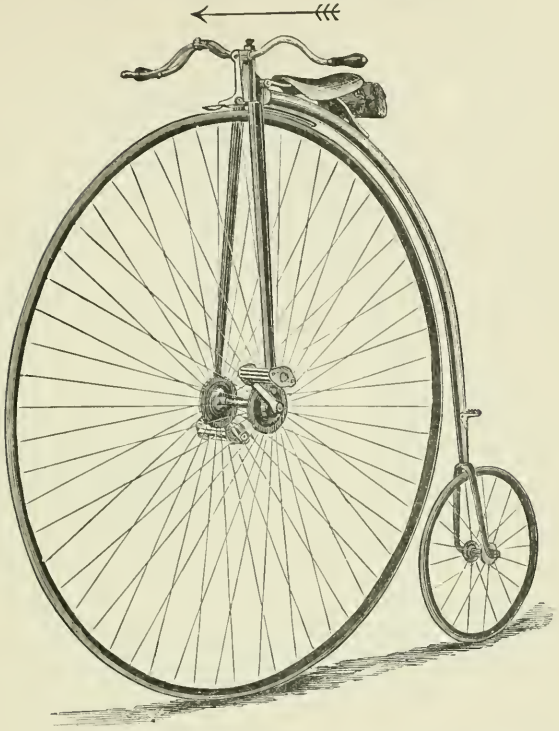
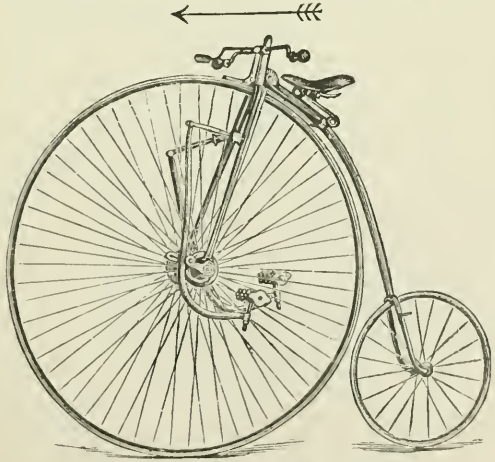


Fig. 4. "'*Xtraordinary*" *Safety Bicycle with elliptical lever action.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 5. "*Facile*" *Safety Bicycle with lever action.*

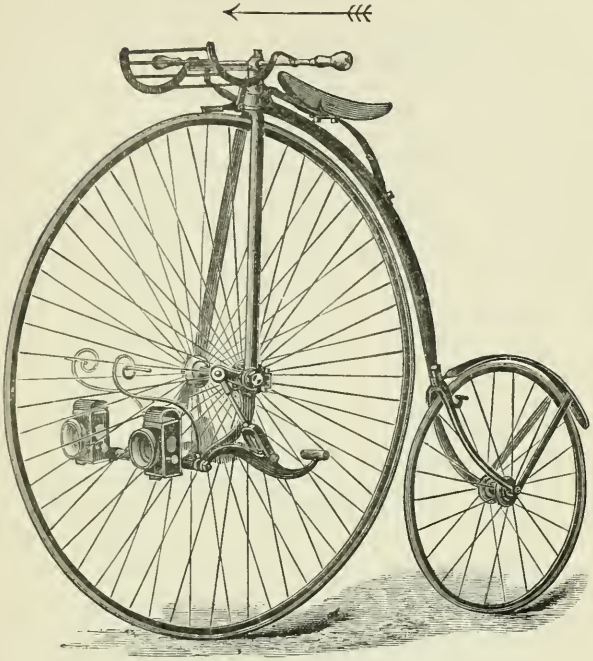
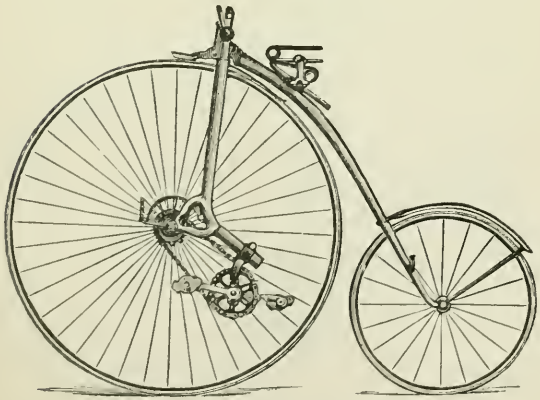


Fig. 6. "*Challenge*" *Safety Bicycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 7. *"Kangaroo" Safety Bicycle with geared rotary action.*

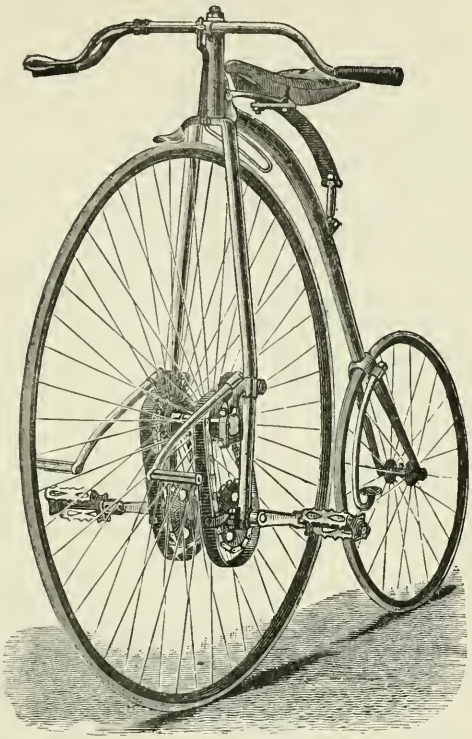
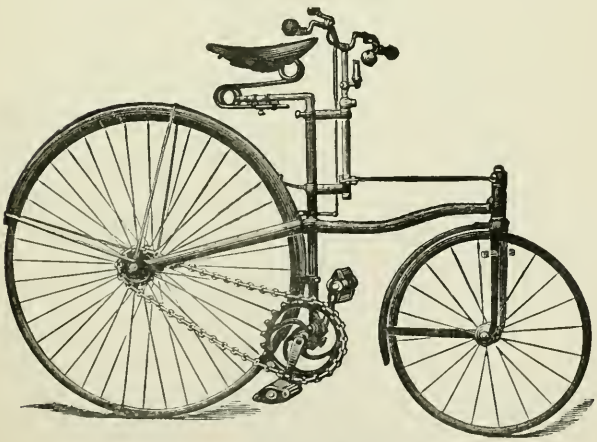


Fig. 8. *"Birmingham Small Arms" Safety Rear-driving Bicycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 9. "*American Star*" *Rear-driving Bicycle.*

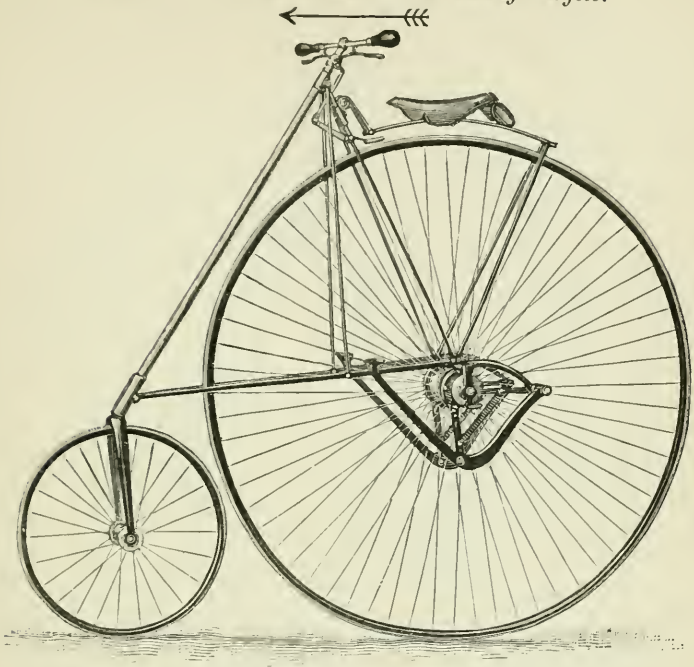
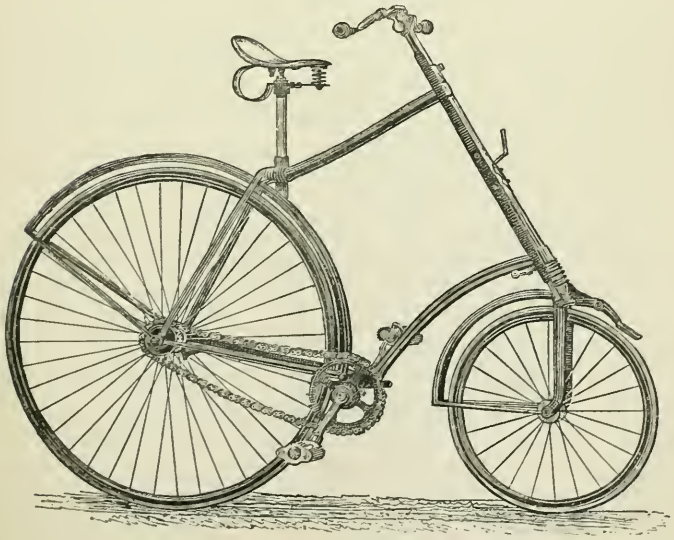


Fig. 10. "*Humber*" *Safety Rear-driving Bicycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 11. *"Rover" Safety Bicycle with large Front-steering wheel.*

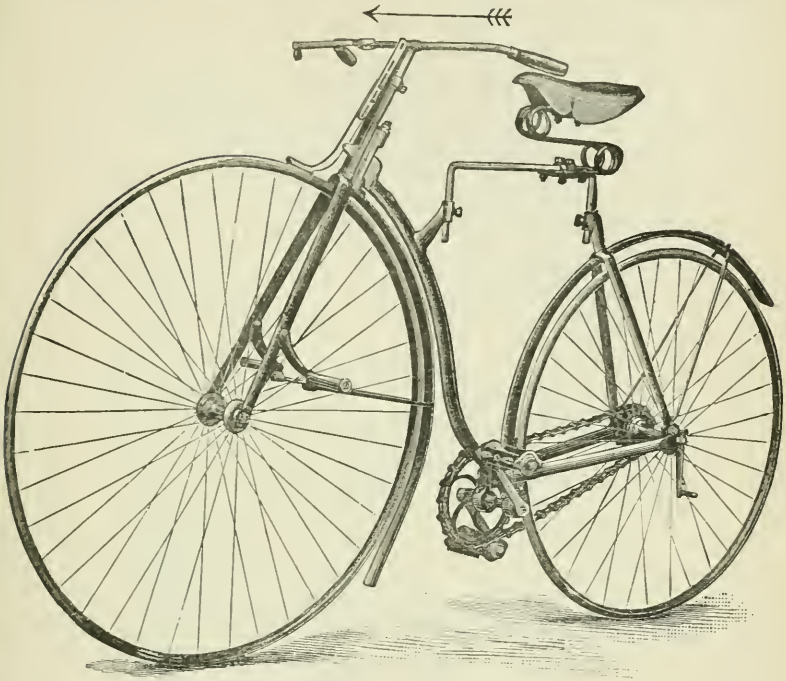
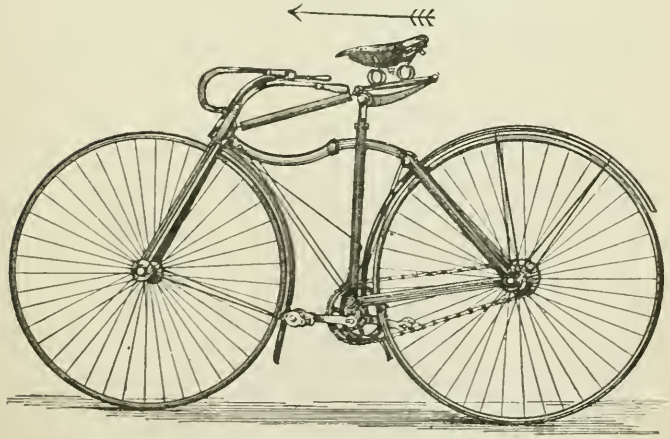


Fig. 12. *"Kaiser" Safety Bicycle with swinging seat-pillar.*

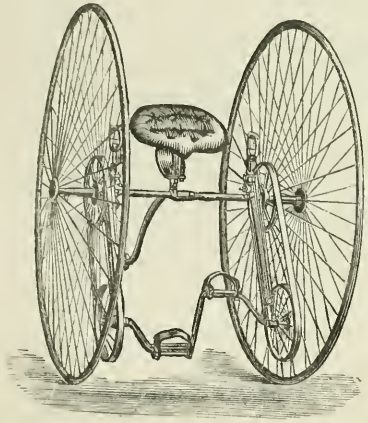


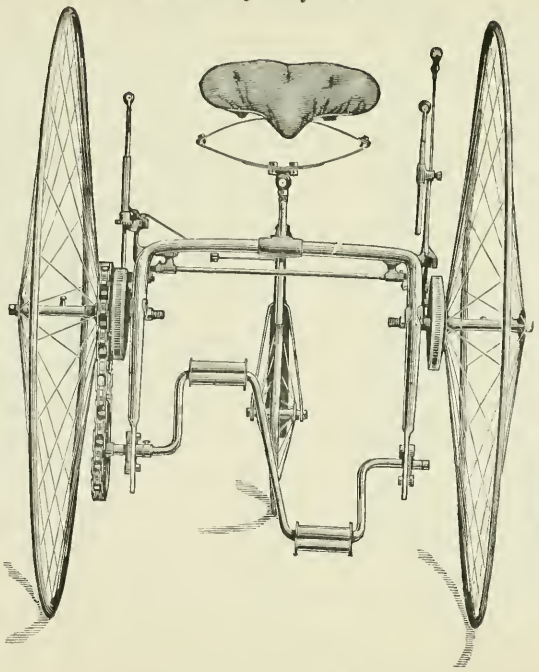
(*Proceedings Inst. M.E.* 1886.)

Fig. 14. *"Meteor" Rear-steering Tricycle, driving only one front wheel.*

Fig. 15. *"Rover" Front-driving Tricycle driven through Fowler balance-gear.*

Fig. 13.
"Otto" Dicycle.





(*Proceedings Inst. M.E.* 1886.)

Fig. 16. "*Humber*" *Tricycle with Fowler balance-driving gear.*

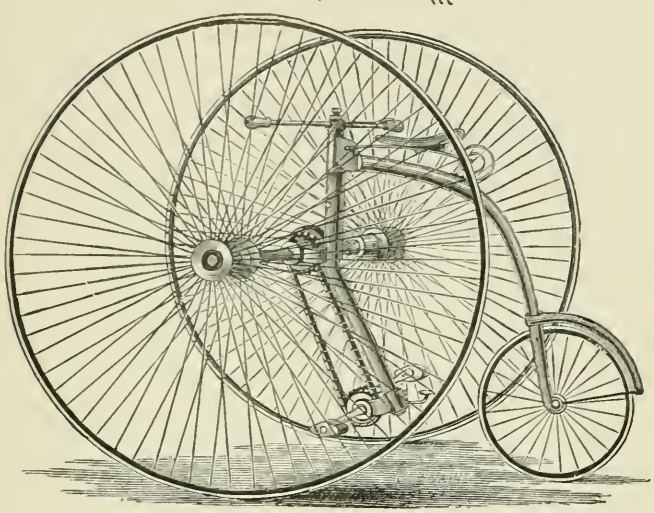
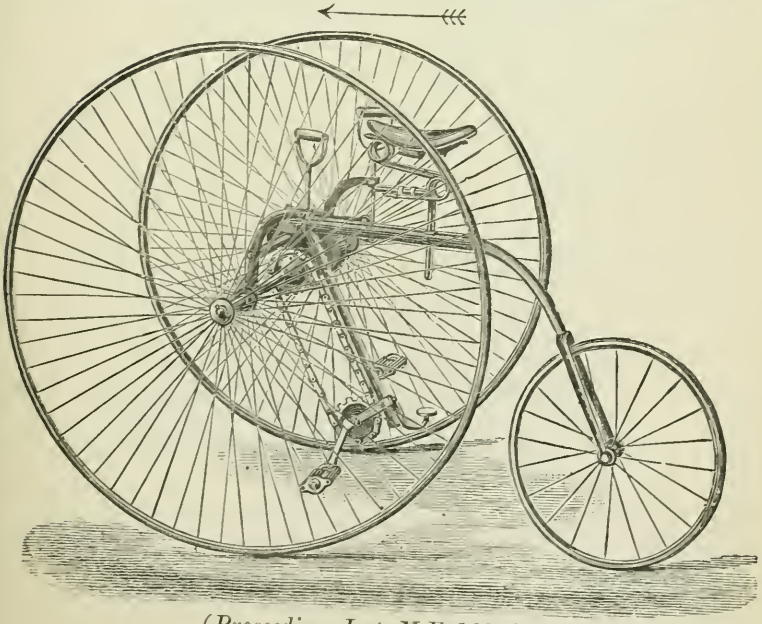


Fig. 17. "*Cruiser*" *Tricycle with Sparkbrook balance-driving gear.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 18. *"Monarch" Rotary Tricycle with swinging pedals and double clutch-driving gear.*

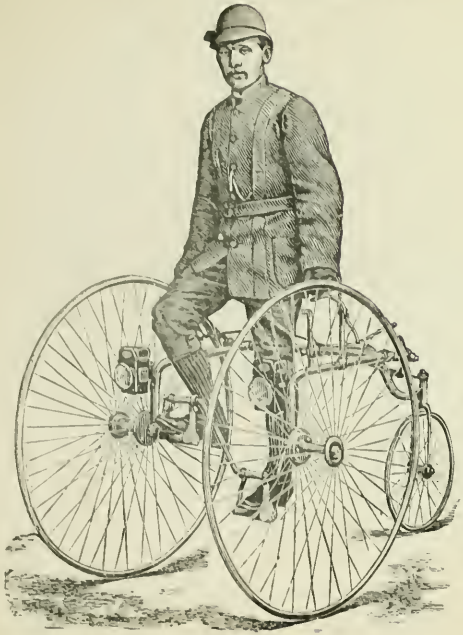


Fig. 19.
"Excelsior" Tricycle driving only one of two front wheels.

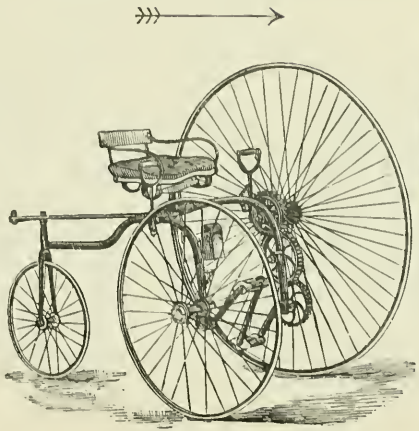
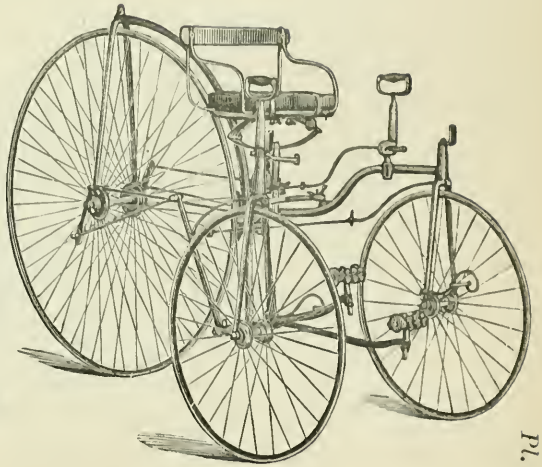


Fig. 20.
"Challenge" Tricycle with single Rear-driving wheel driven by Levers.



(Proceedings Inst. M.E. 1886.)

Pl. 22.

Fig. 21. "*Cheylesmore*" *Front-driving Tricycle with double clutch-driving gear.*

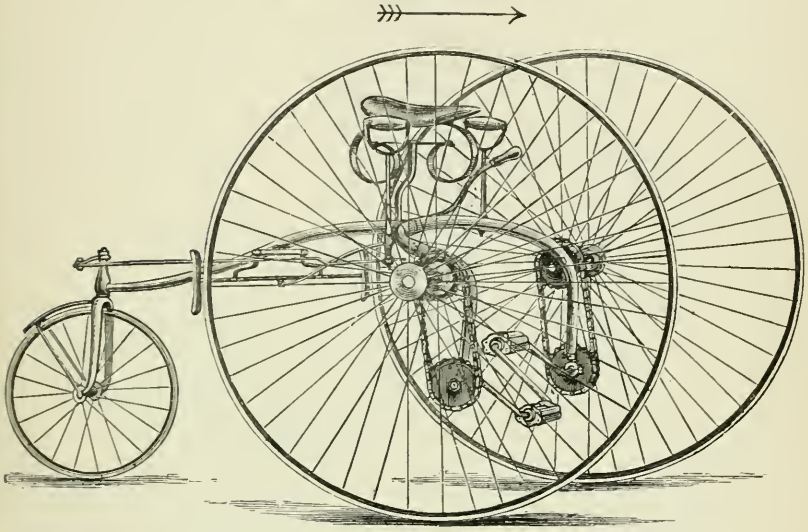
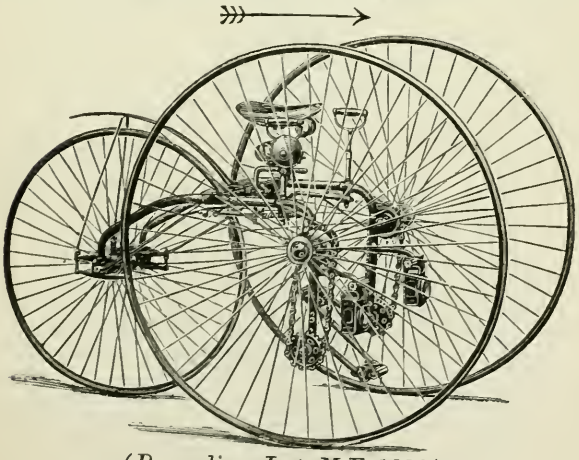


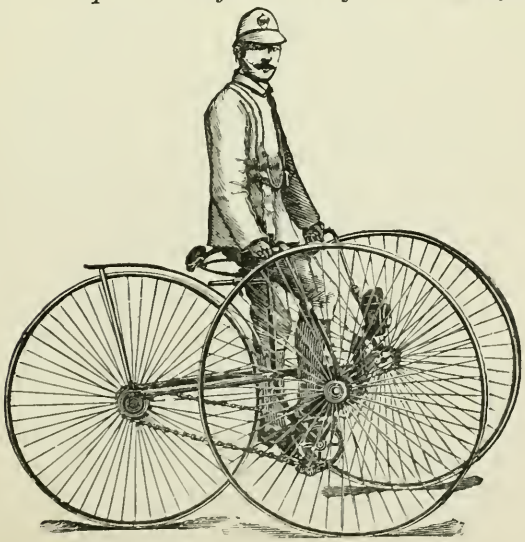
Fig. 22. "*Quadrant No.* 1" *Front-driving Tricycle with double clutch-driving gear.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 23. *"Gnat" Tricycle with single Rear-driving wheel.*

Fig. 24. *"Emperor" Tricycle with single Rear-driving wheel.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 25. *"Royal Salvo" Rear-driving Tricycle with balance-driving gear.*

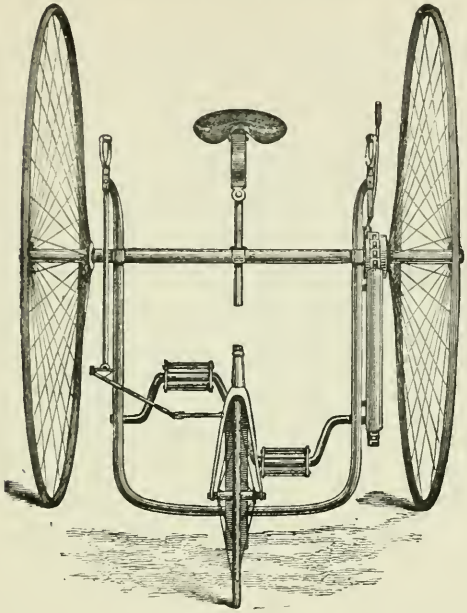
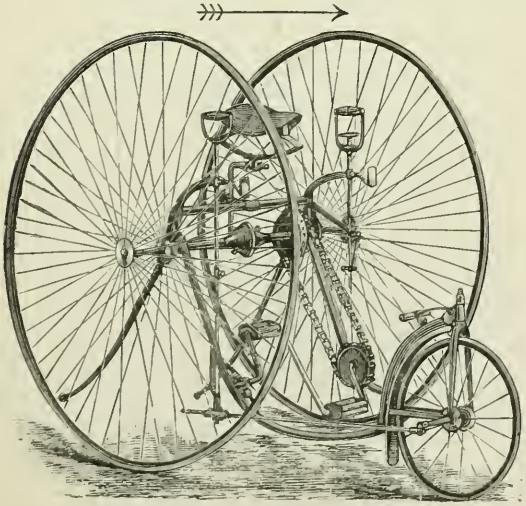


Fig. 26. *"Sparkbrook" Tricycle with balance-driving gear.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 27. "*Quadrant No.* 8" *Rear-driving Tricycle with balance-driving gear.*

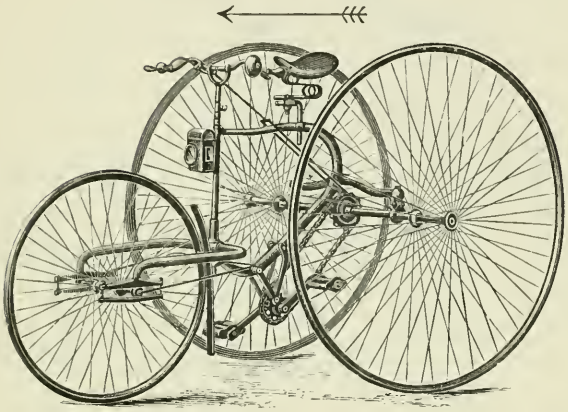
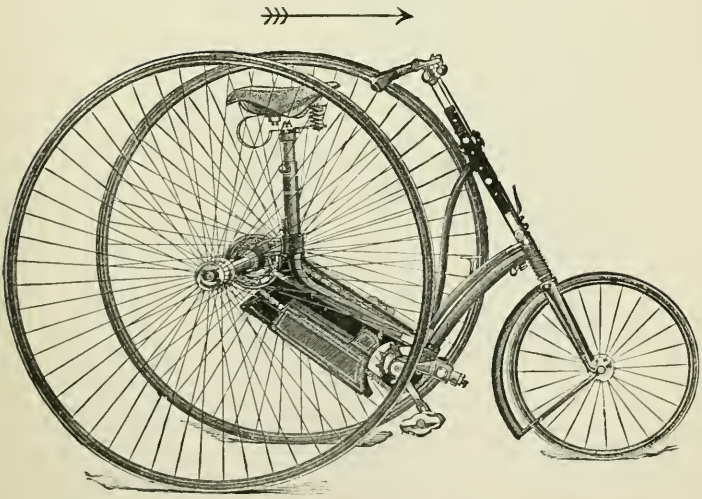


Fig. 28. "*Cripper*" *Rear-driving Tricycle with balance-driving gear.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 29. "*Royal Mail*" *Two-track Tricycle with balance-driving gear.*

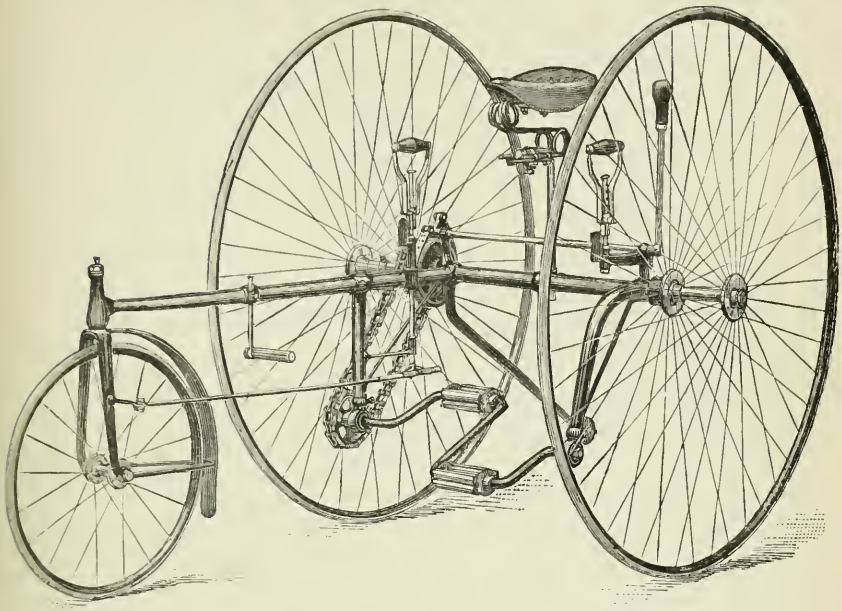
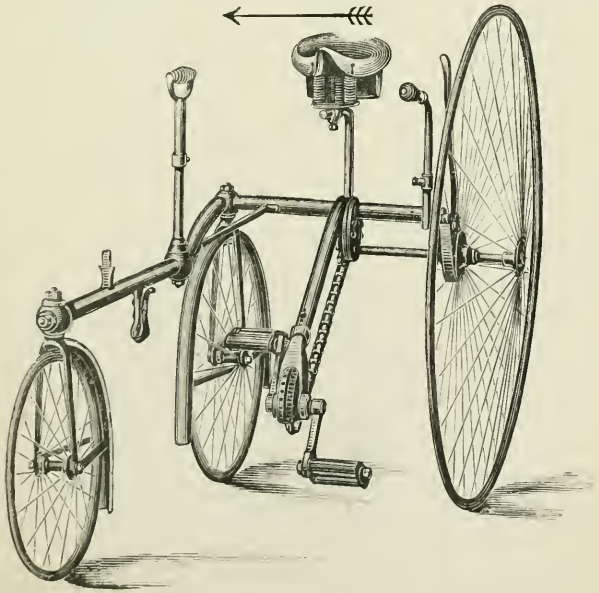


Fig. 30. "*Grosvenor*" *Two-track Tricycle with single Rear-driving wheel.* (*See Fig.* 40.)



(*Proceedings Inst. M.E.* 1886.)

Fig. 31.
"Rudge" Two-track Tricycle with single lateral driving-wheel.

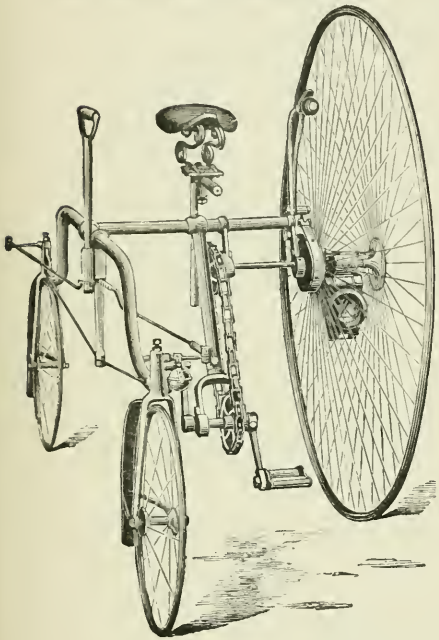


Fig. 32.
"Pearce" Sociable Monocycle.

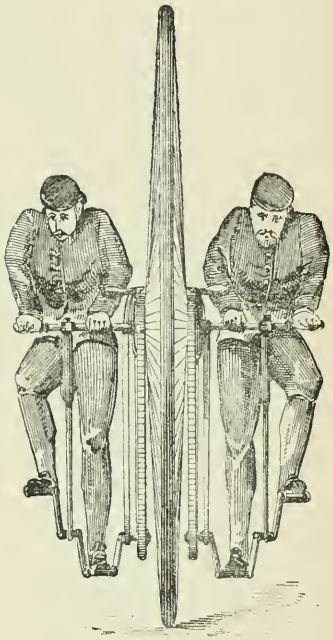
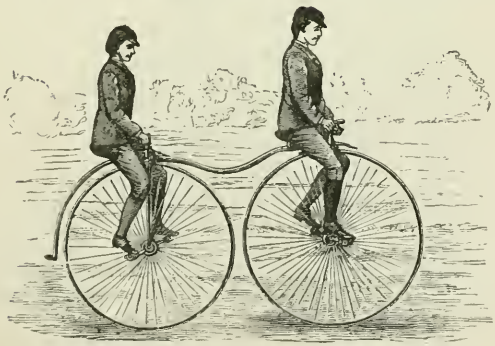


Fig. 33. *Earlier "Rucker" Tandem Bicycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 34. *Later "Rucker" Tandem Bicycle.*

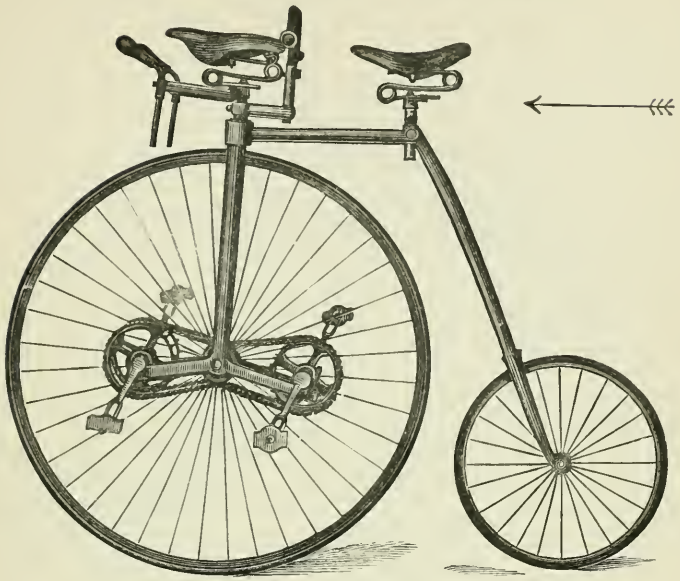
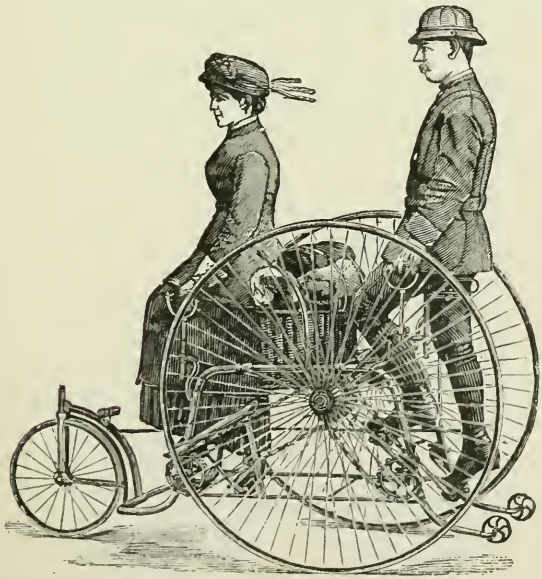


Fig. 35. *"Centaur" Front-steering Tandem Tricycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 36. "*Humber*" *Tandem Tricycle.*

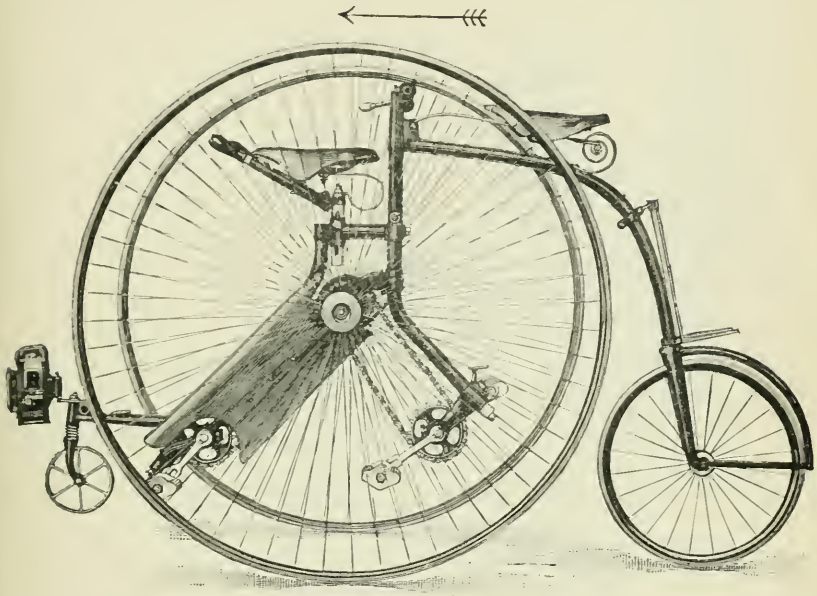
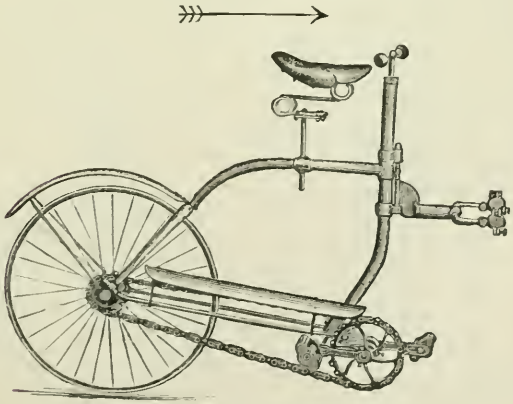


Fig. 37. "*Krao*" *Trailing Frame driving its own wheel, for attachment behind tricycles of class B.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 38. *Coventry Chair.*

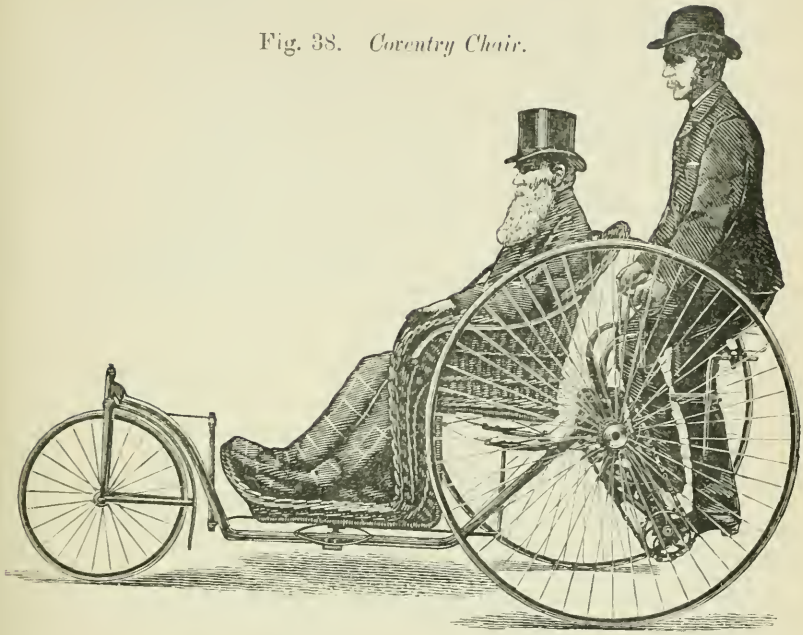


Fig. 40. "*Grosvenor*" *Sociable, loose half.* (*See Fig.* 30.)

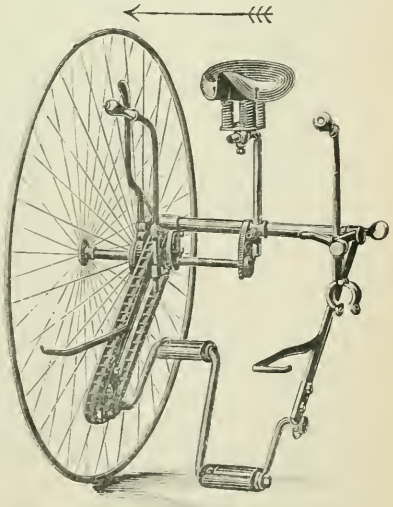
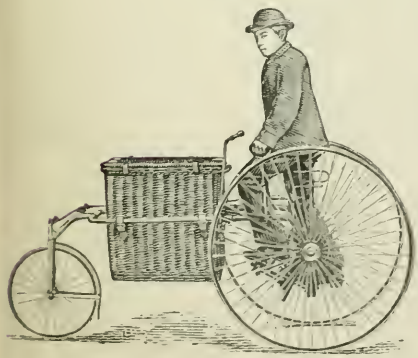
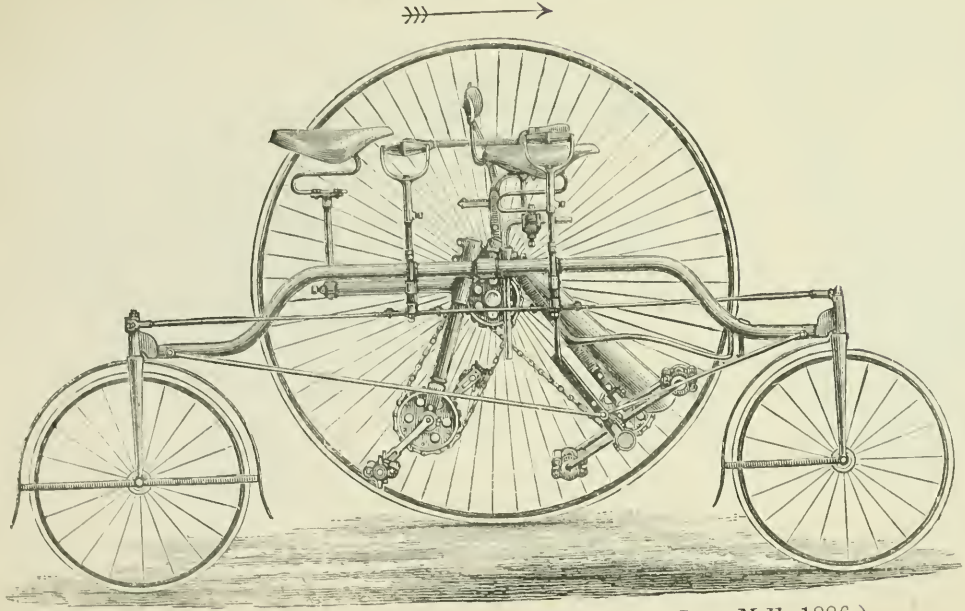


Fig. 39.
"*Despatch*" *Carrier Tricycle.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 41.
"Rudge" Tandem Tricycle.



(*Proceedings Inst. M.E.* 1886.)

Fig. 42. *"Coventry" Convertible Sociable.*

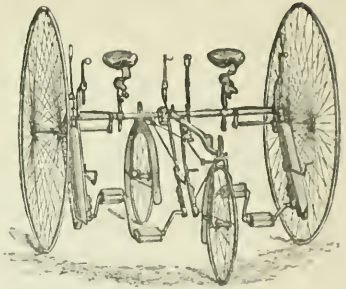


Fig. 43. *"Coventry" Convertible Sociable with addition detached.*

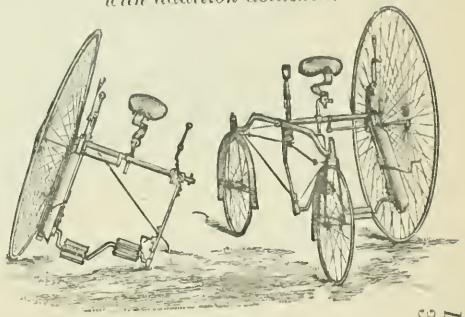
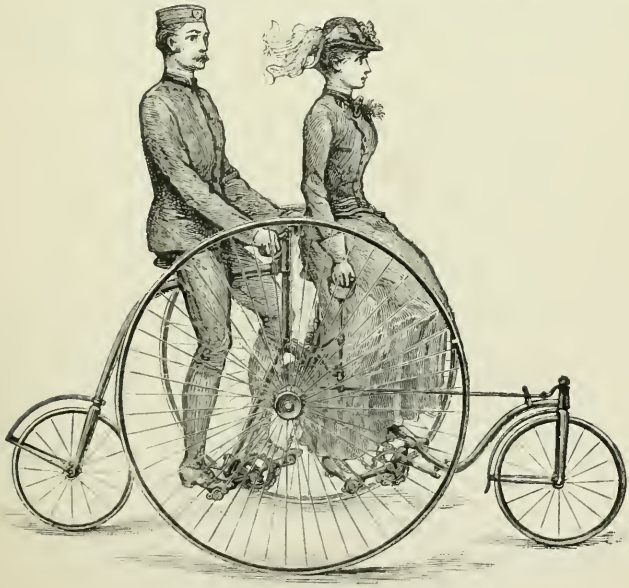


Fig. 44. "*Royal Mail*" *Two-track Tandem.*

Fig. 45. "*Club*" *Four-wheeled Tandem.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 16. *"Carver" Tandem Tricycle with trailing frame.*

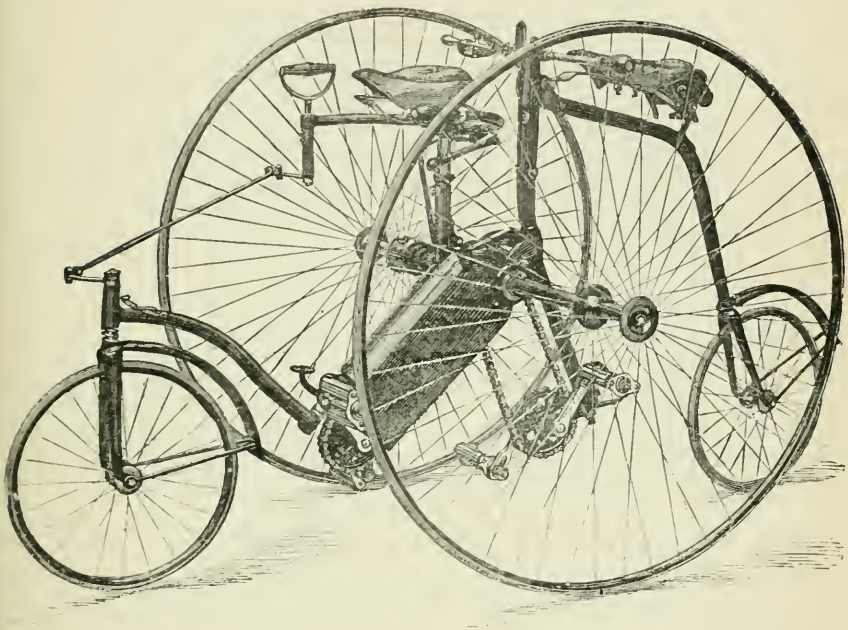
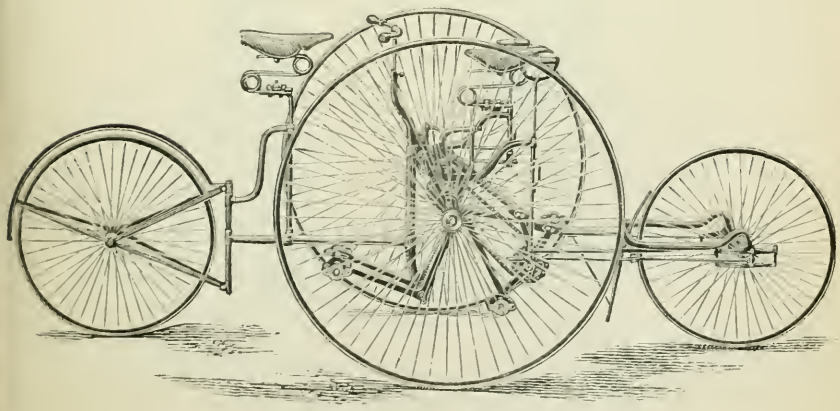


Fig. 17. *"Quadrant" Four-wheeled Tandem.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 48. *Four-wheeled Tandem with Swivel Coupling.*

Humber. *Cruiser.*

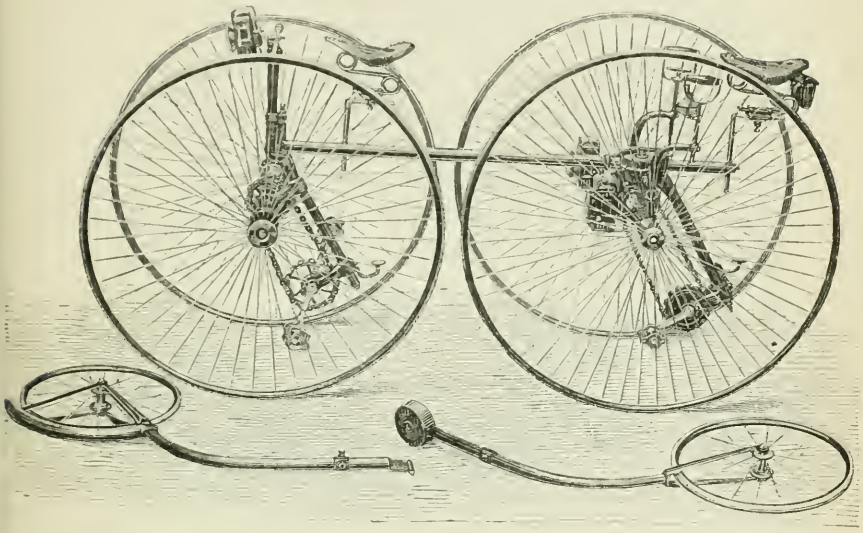
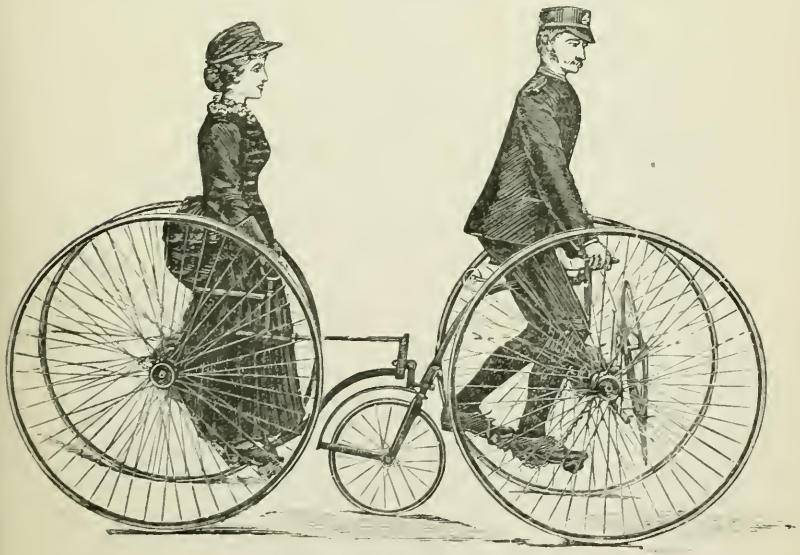


Fig. 49. *Gibbons' Five-wheeled Combination Tandem.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 50. *"Devon" Tricycle with adjustable double frame.*

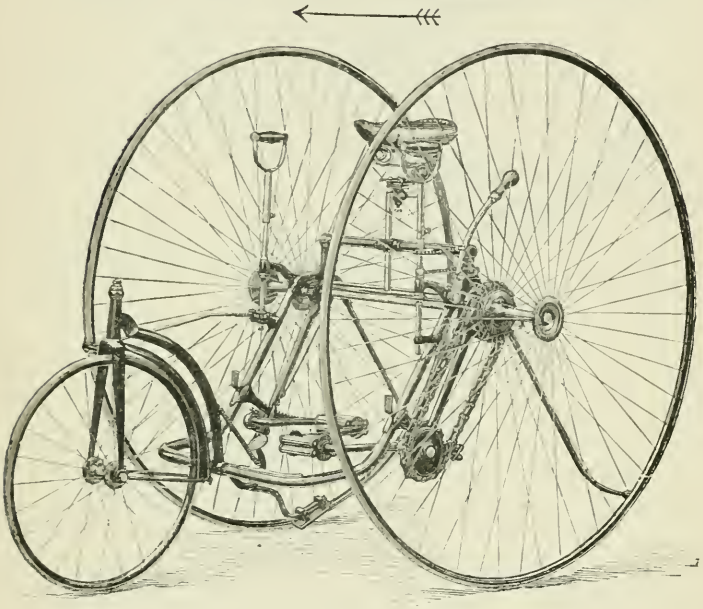
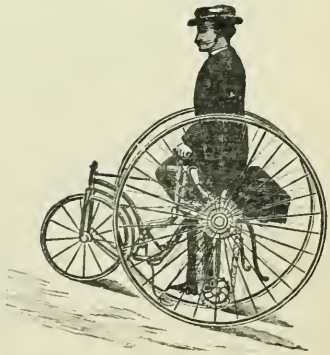


Fig. 51.
Uphill with rigid frame.

Fig. 52.
Uphill with adjustable frame.



(*Proceedings Inst. M.E.* 1886.)

Fig. 53. "*Club*" *Sliding Seat.*

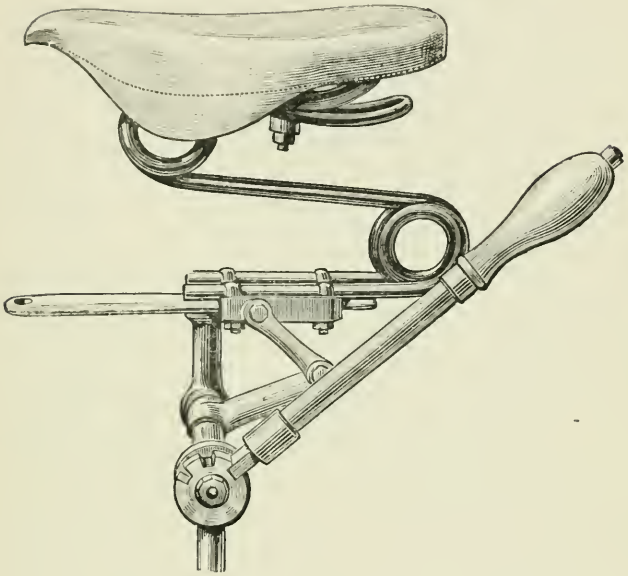
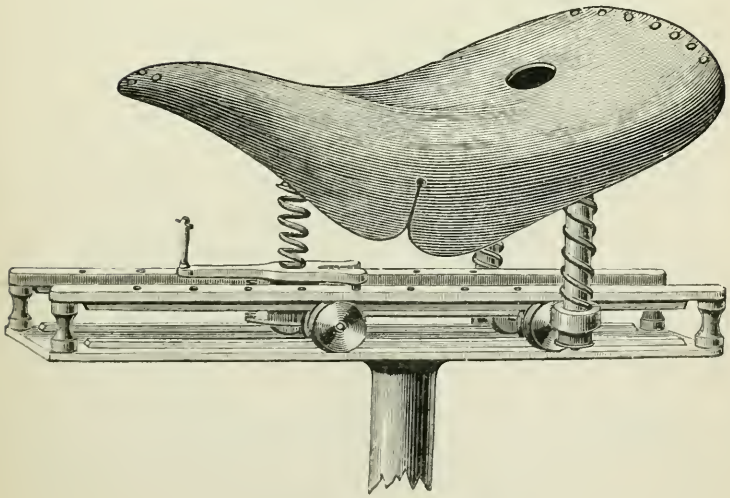


Fig. 54. "*Matchless*" *Sliding Seat.*



(*Proceedings Inst. M.E.* 1886.)

Fig. 55. *Safety Bicycle with adjustable frame.*

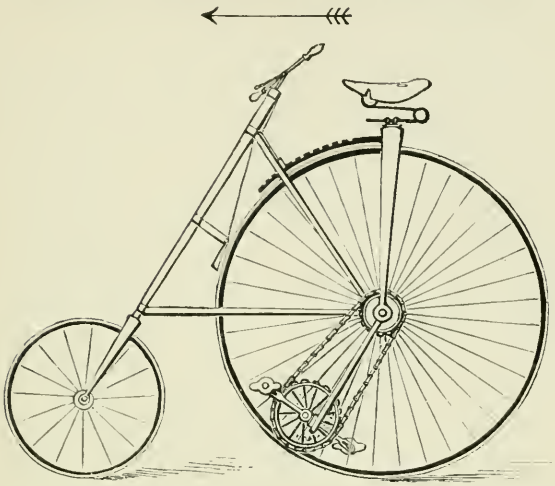
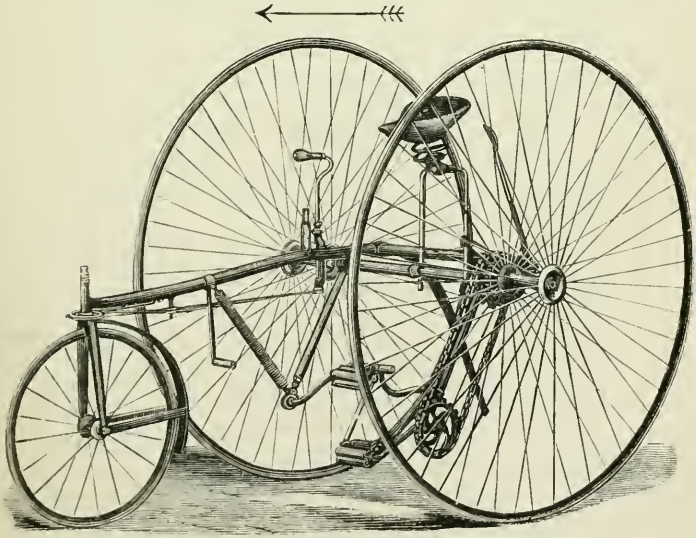


Fig. 56. *"Spinaway" Tricycle with automatic balanced frame.*



(*Proceedings Inst. M.E.* 1886.)

Spinaway Tricycle.

Fig 57. *Elevation.*

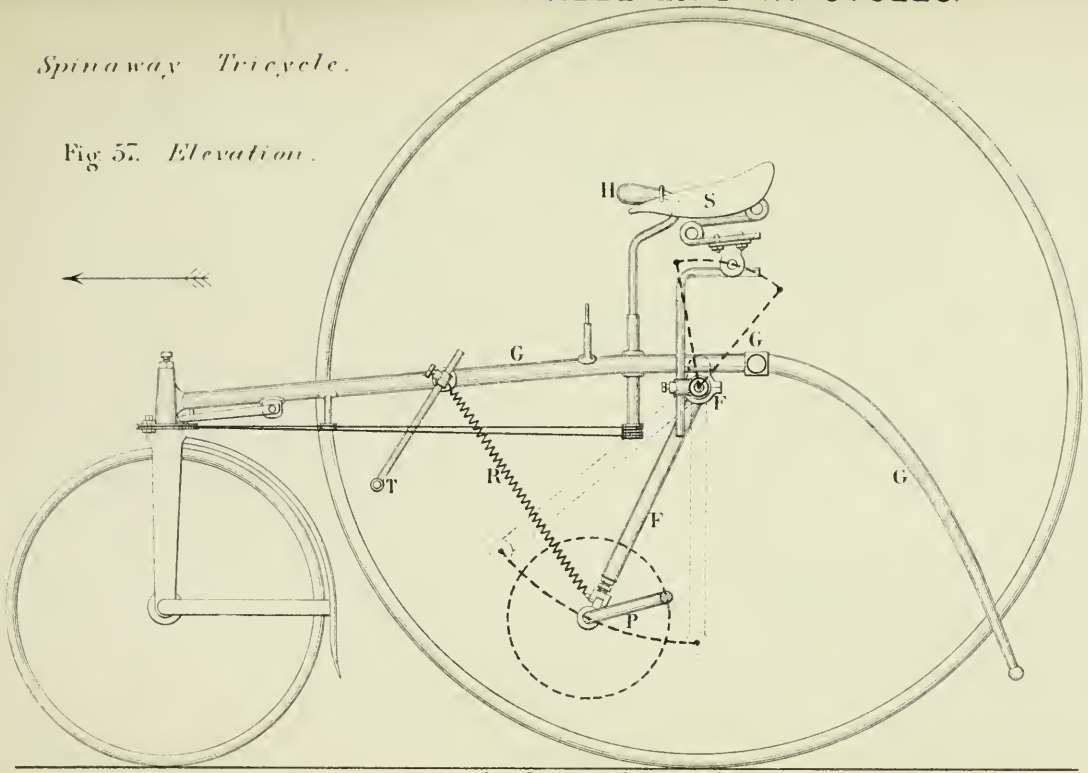
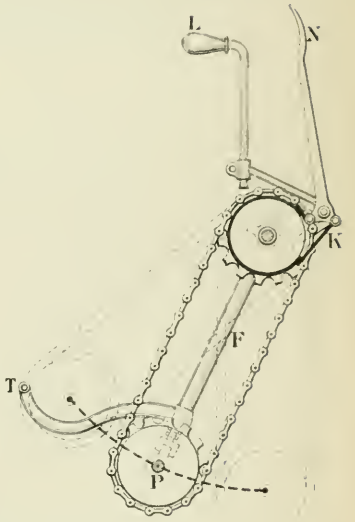


Fig 58. *Elevation of Driving Gear.*

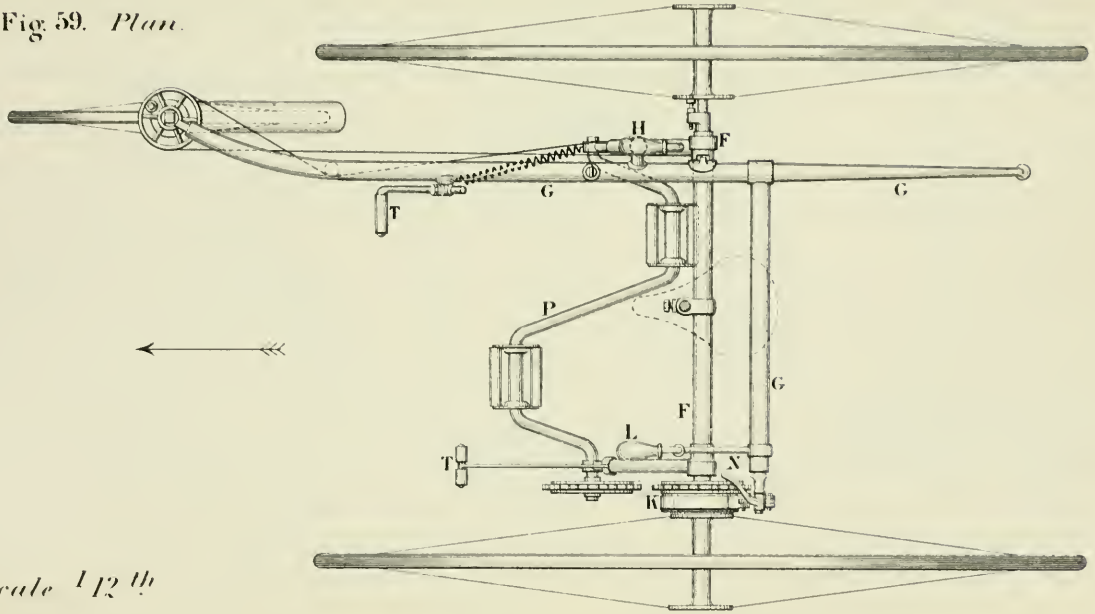


Scale 1 12 th

Ins. 12 6 0 1 2 3 Feet

Spinaway Tricycle.

Fig. 59. *Plan.*



Scale 1/12 *th*

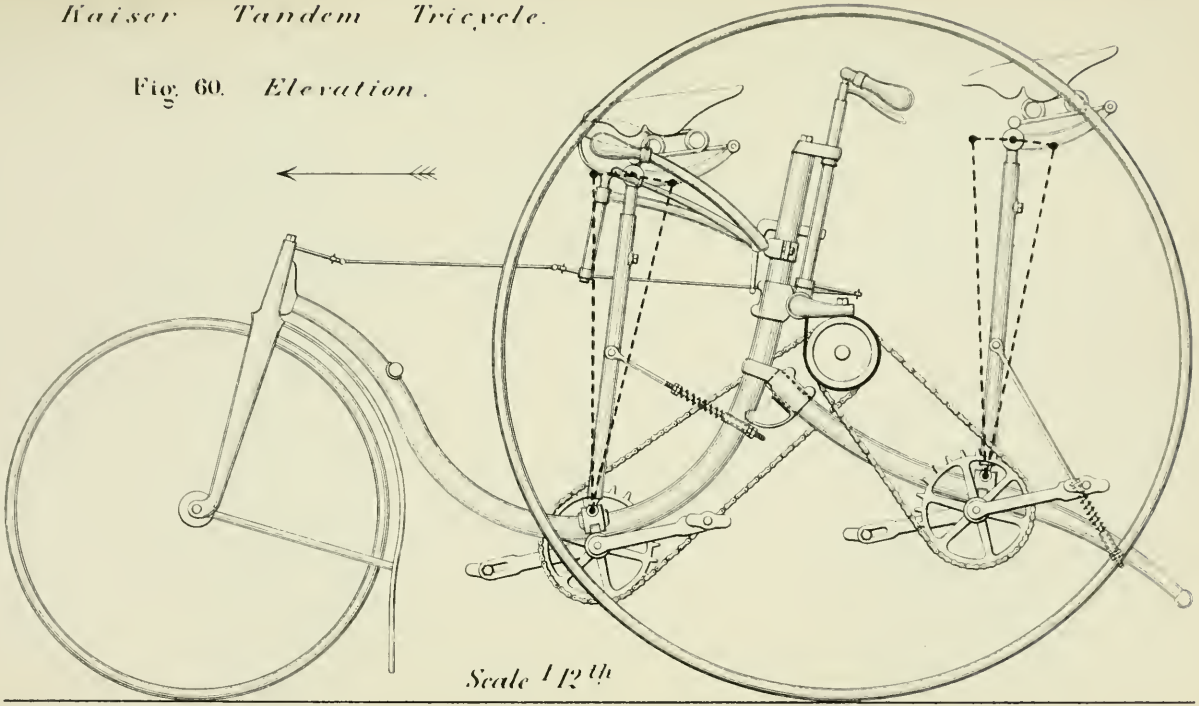
(Proceedings Inst. M. E. 1886.)

Ins. 12 6 0 1 2 3 Feet

Plate 40.

Kaiser Tandem Tricycle.

Fig. 60. *Elevation.*



Scale 1/12th

Ins. 12 6 0 1 2 3 Feet 4

(Proceedings Inst. M.E. 1886.)

Plate 41.

WHEEL LOAD IN CYCLES.

Fig. 61.
"Hobby Horse."
(See Fig. 1.)

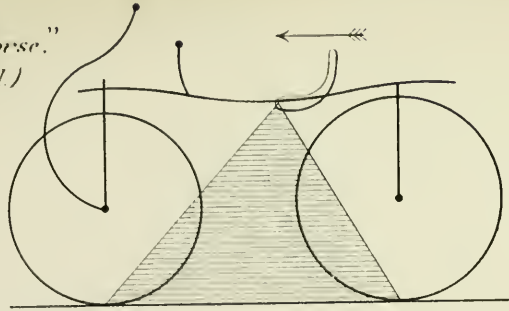


Fig. 62.
"Boneshaker."
(See Fig. 2.)

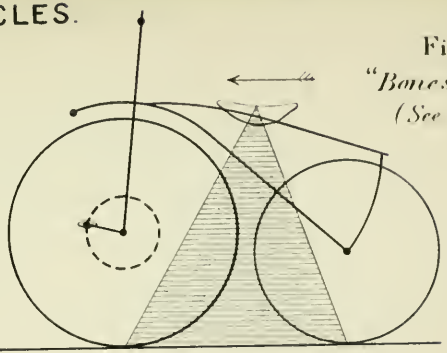


Fig. 63.
Present
Bicycle.
(See Fig. 3.)

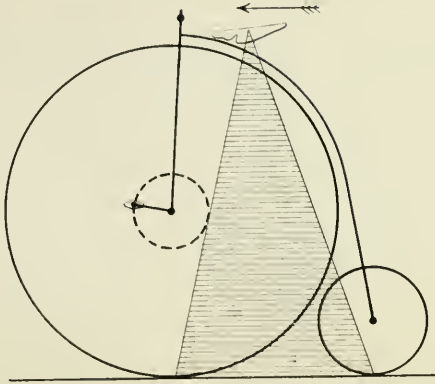
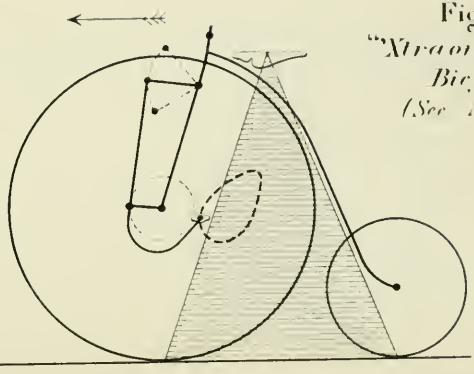


Fig. 64.
"Xtraordinary"
Bicycle.
(See Fig. 4.)



(Proceedings Inst. M. E. 1886.)

Scale 1/30th

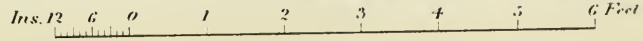
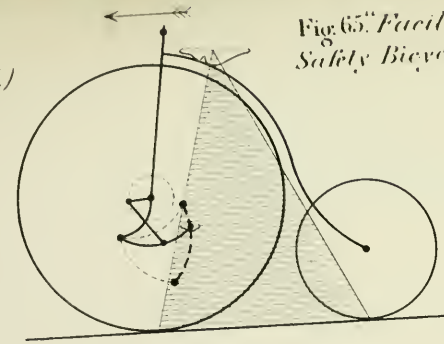


Plate 42.

WHEEL LOAD IN CYCLES.



(See Fig. 5.)

Fig. 65. "Facile" Safety Bicycle.

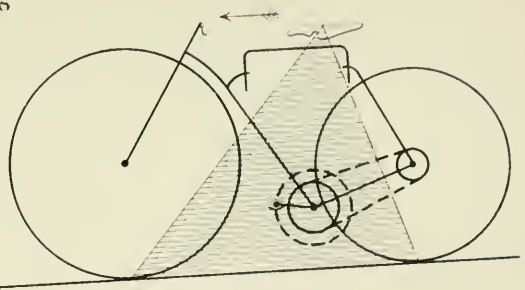


Fig. 69. "Rover" Safety Bicycle. (See Fig 11.)

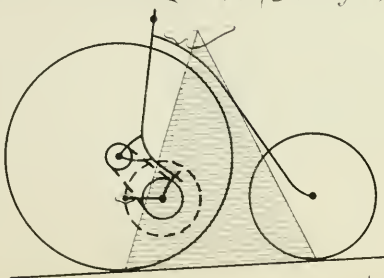


Fig. 66. "Challenge" Safety Bicycle. (See Fig. 6.)

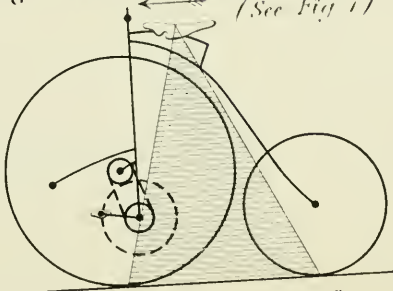


Fig. 67. "Kangaroo" Safety Bicycle. (See Fig 7.)

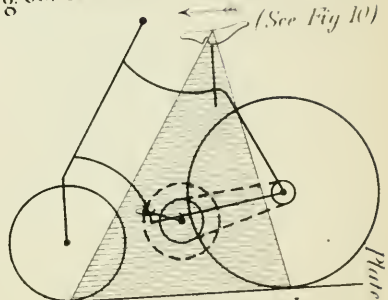
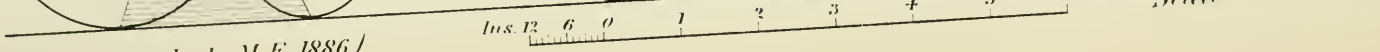


Fig. 68. "Humber" Safety Bicycle. (See Fig 10.)



Scale 1/30th

(Proceedings Inst. M.E. 1886.)

Fig. 70.

Class A.

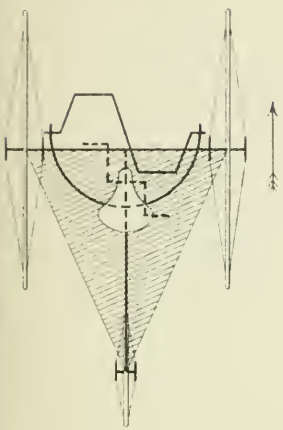


Fig. 71. *Class* B.

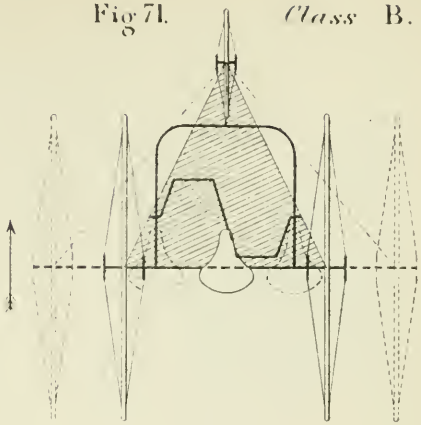


Fig. 72.

Class C.

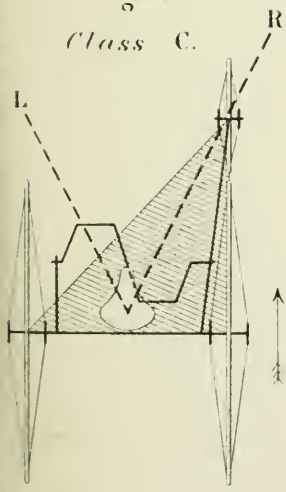
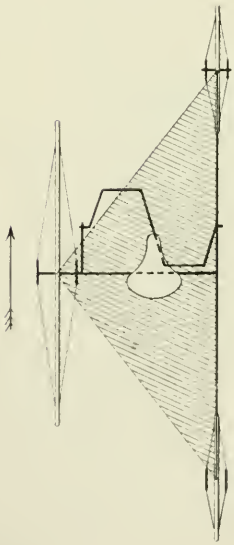


Fig. 73.

Class D.



(Proceedings Inst. M.E. 1886.)

Scale $\frac{1}{30}$ *th*

Ins 12 6 0 1 2 3 4 5 6 *Feet.*

Fig. 74.

Classes A and B combined.

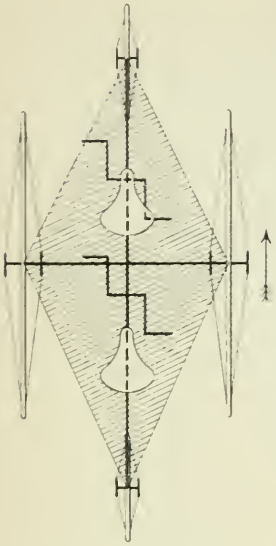


Fig. 75.

Class C duplicated.

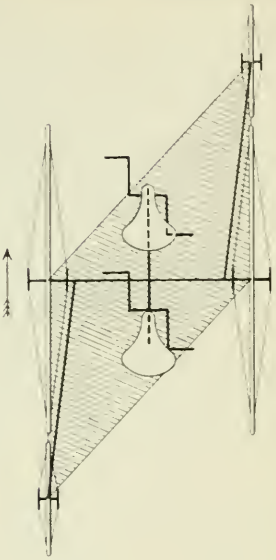


Fig. 76. *Class D duplicated.*

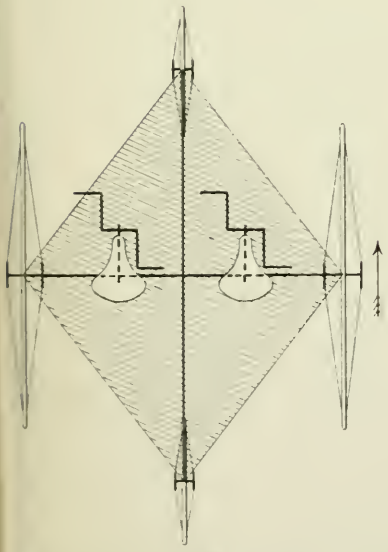
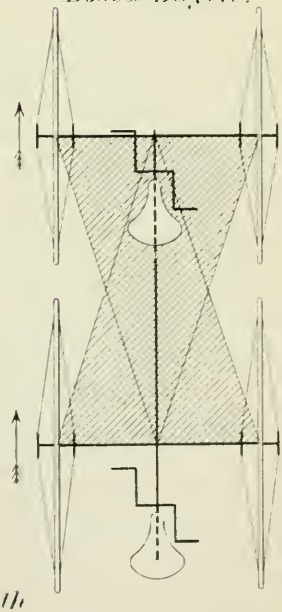


Fig. 77.

Double Dicycle.



(Proceedings Inst. M. E. 1886) *Scale* $\frac{1}{30}$*th*

Ins 12 6 0 1 2 3 4 5 6 Feet

WHEEL LOAD IN CYCLES.

Double-driving Clutch.

Plate 46.

Fig. 78.

Side Elevation.

Scale 3/4 size.

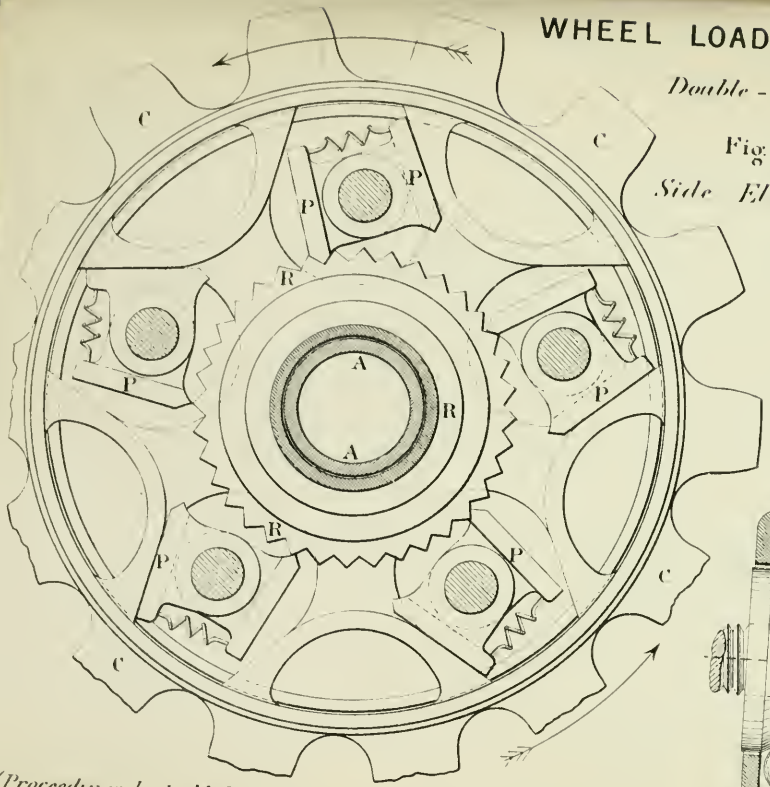


Fig. 79.

Cross Section.

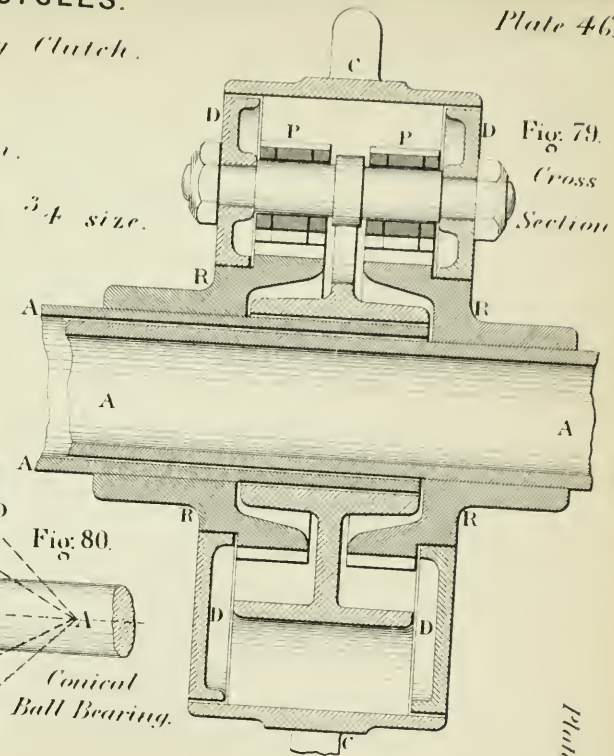
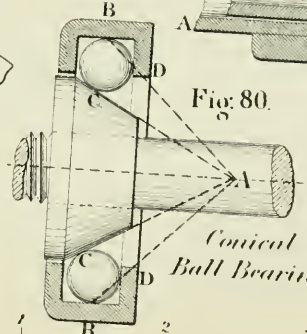
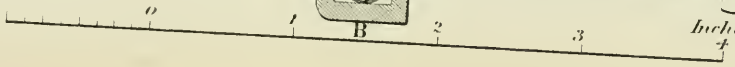


Fig. 80.

Conical Ball Bearing.





Scale 3/4 size.

(Proceedings Inst. M. E. 1886.)

Plate 46.

RAISING A WRECK.

After Part of the Wrecked Steamship "Peer of the Realm."

Fig 1. *Longitudinal Section.*

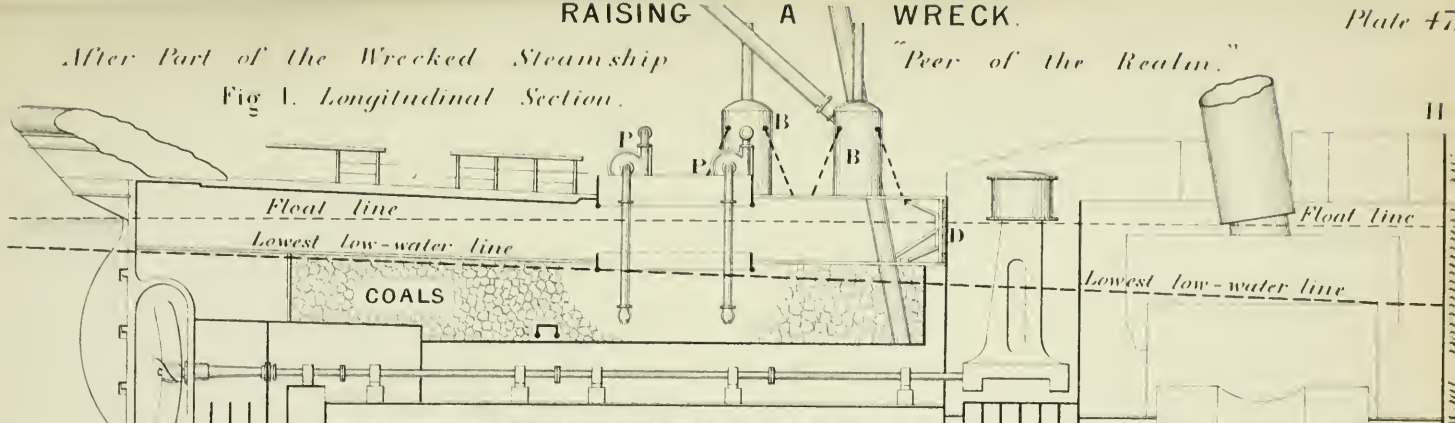
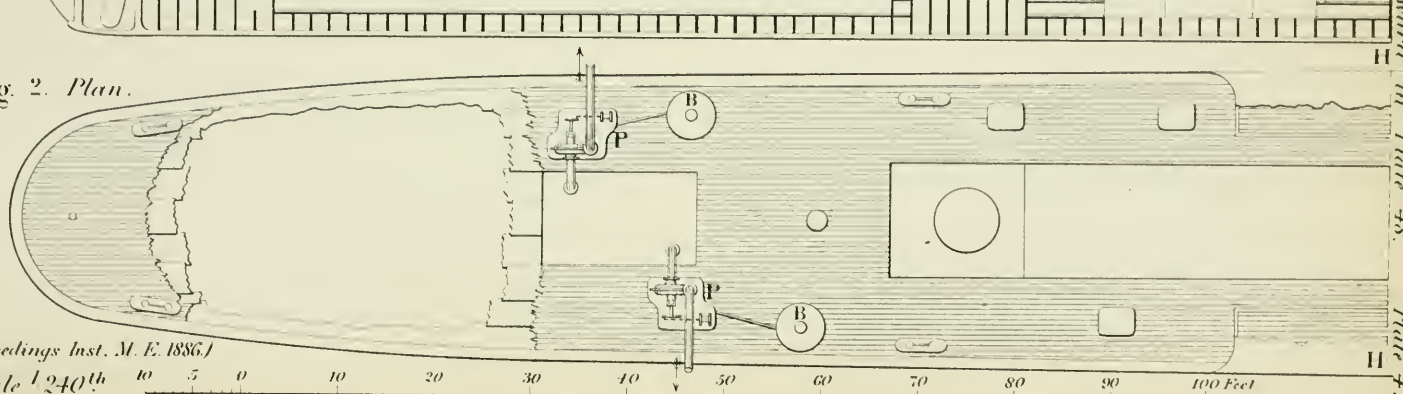


Fig. 2. *Plan.*



(Proceedings Inst. M. E. 1886.)

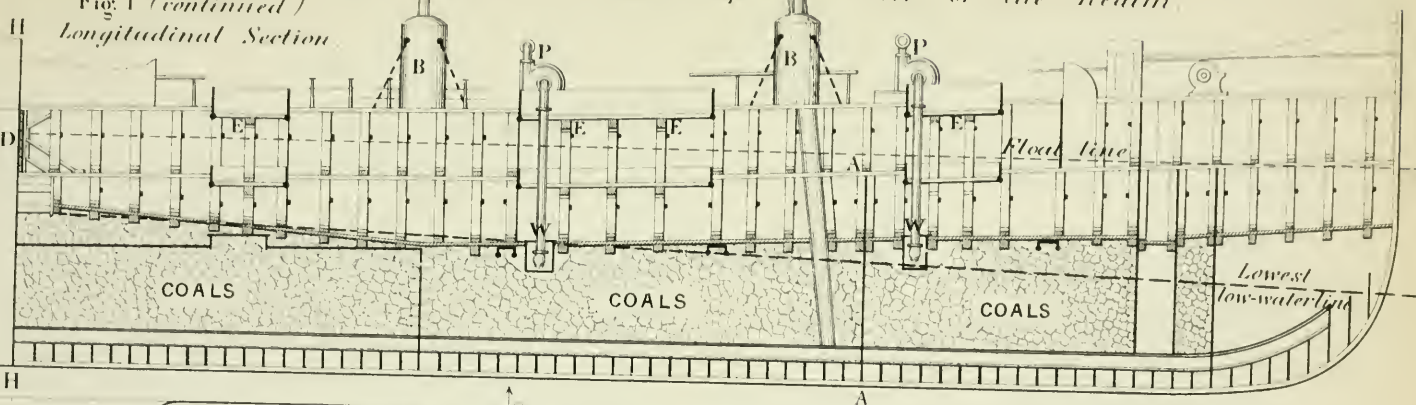
Scale 1/240th

10 5 0 10 20 30 40 50 60 70 80 90 100 Feet

RAISING A WRECK.

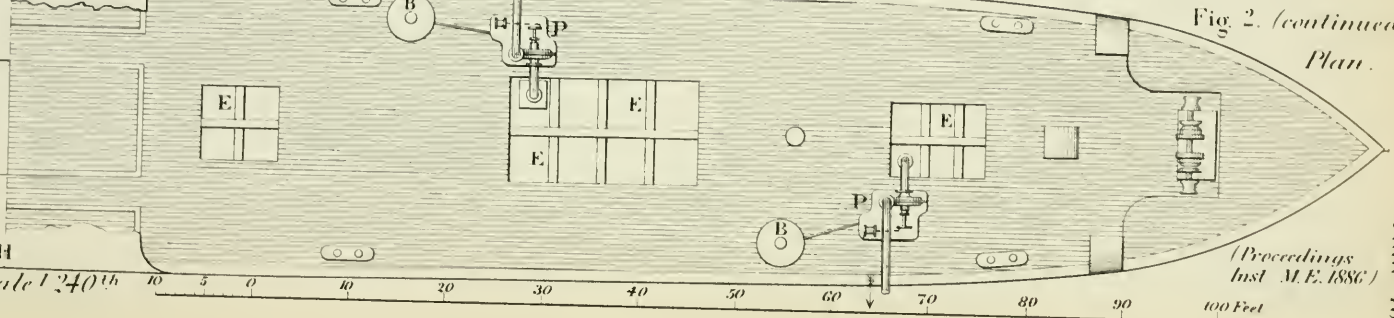
Fore Part of the Wrecked Steamship "Peer of the Realm"

Fig. 1 *(continued)* *Longitudinal Section*



See continuation of this Plate 47.

Fig. 2. *(continued)* *Plan.*



(Proceedings Inst M.E. 1886)

Plate 48.

Raising the Wrecked Steamship "Peer of the Realm"

Fig. 3. *Cross Section of Fore Part.*

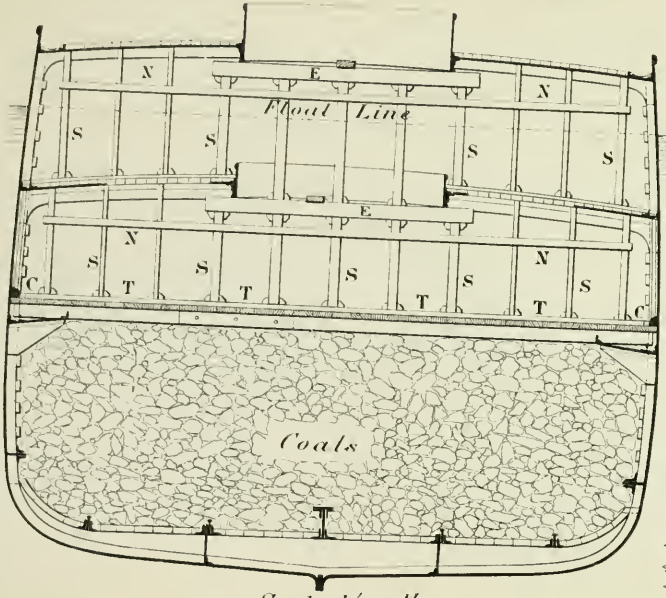


Fig. 5 *Position of Wreck at Lundy Island*

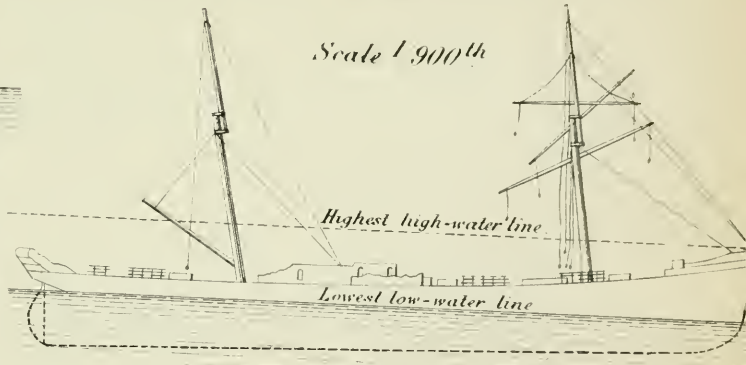
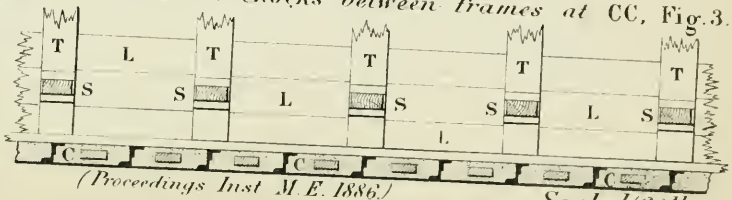


Fig. 4.

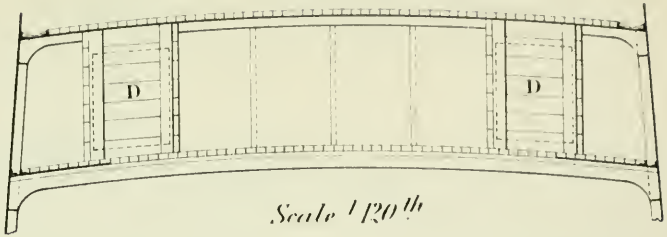
Plan of Chocks between frames at CC, Fig. 3.



(Proceedings Inst M.E. 1886.)

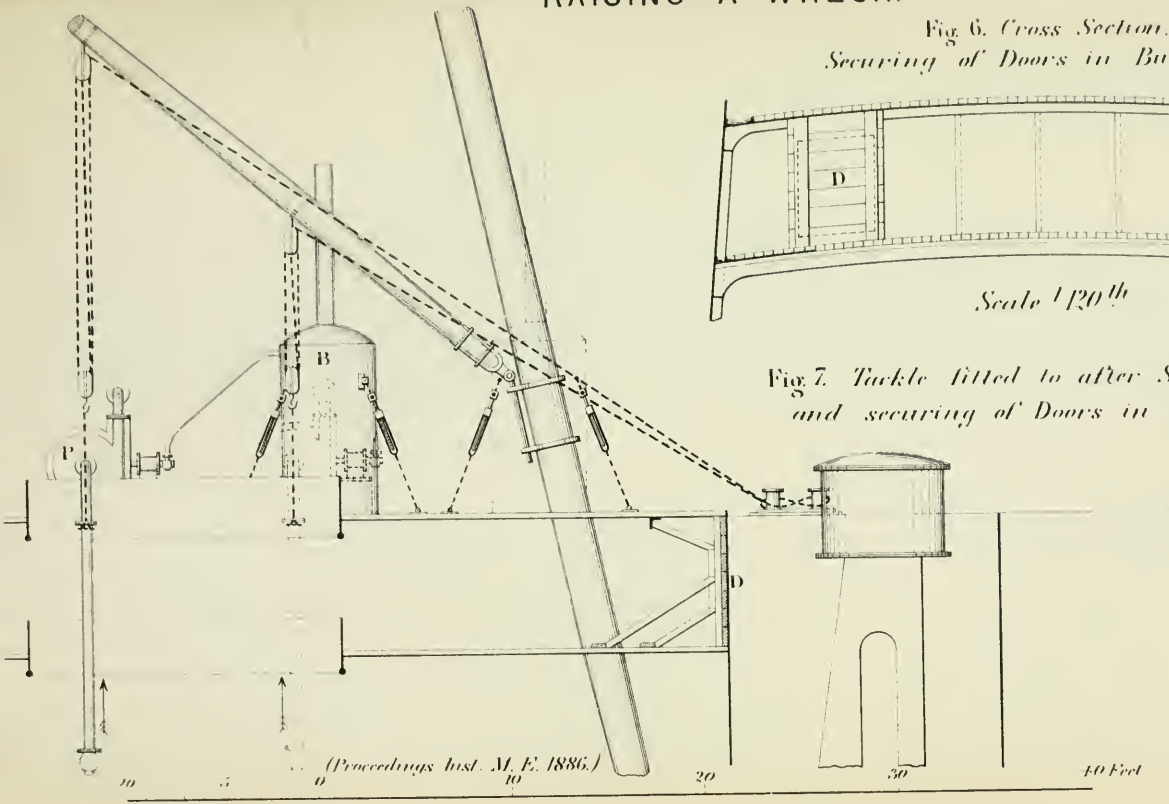
RAISING A WRECK.

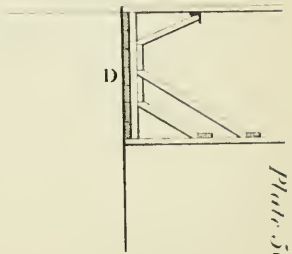
Fig. 6. *Cross Section.*
Securing of Doors in Bulkheads.



Scale 1/20 th

Fig. 7. *Tackle fitted to after Suction Pipes, and securing of Doors in Bulkheads.*





Scale 1/20 th

(*Proceedings Inst. M.E. 1886.*)

Plate 50.

RAISING A WRECK.

Scale 1/900th

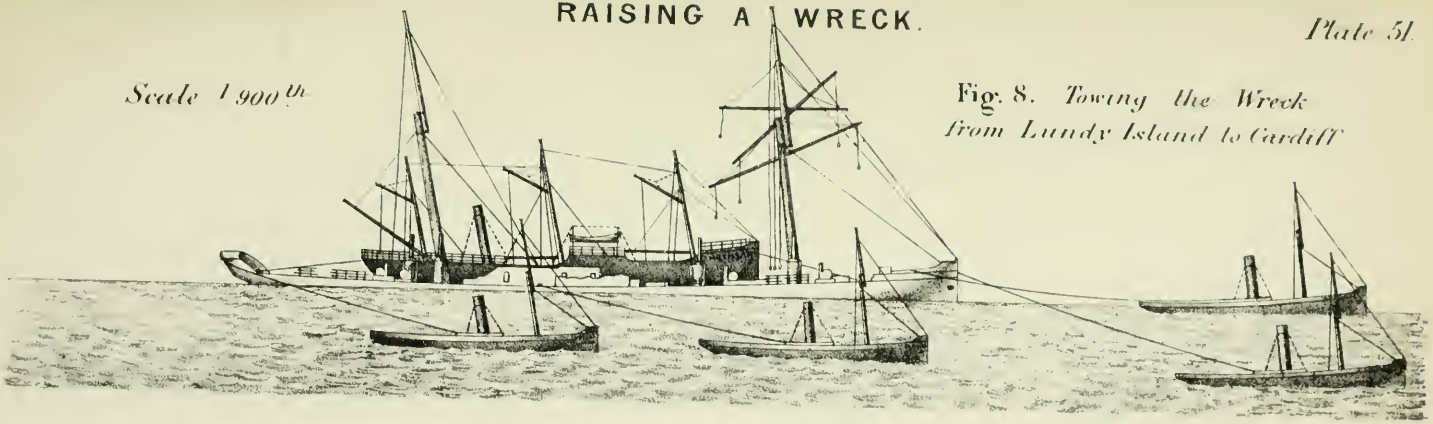


Fig. 8. *Towing the Wreck from Lundy Island to Cardiff*

Fig. 10.

Steamer repaired.

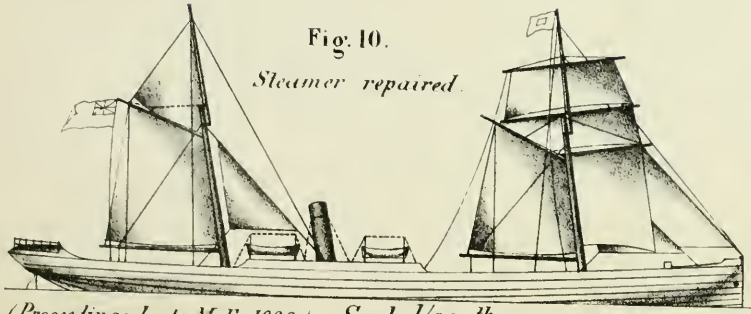
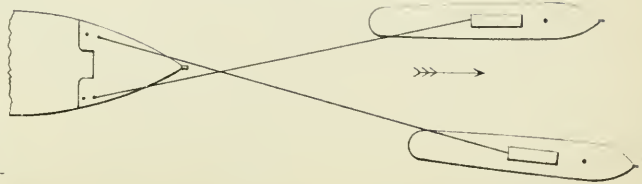


Fig. 9. *Plan of tow ropes from two forward tugs.*



(*Proceedings Inst. M.E. 1886.*) Scale 1/900th

0 50 100 150 200 250 300 Feet

Plate 51.

Fig. 1. *Curves of Vapour Tensions.*

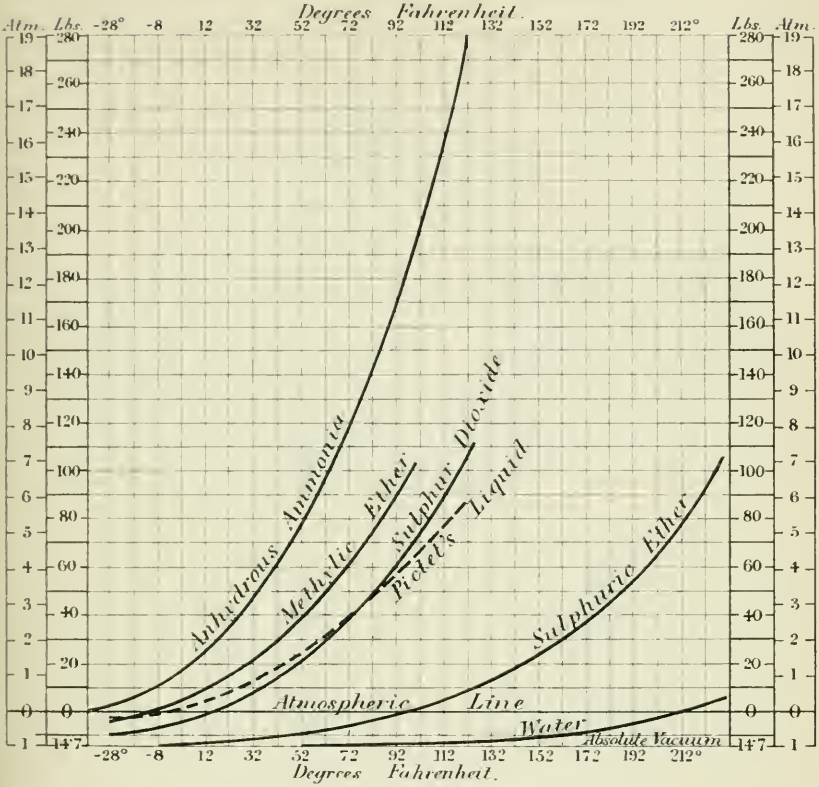
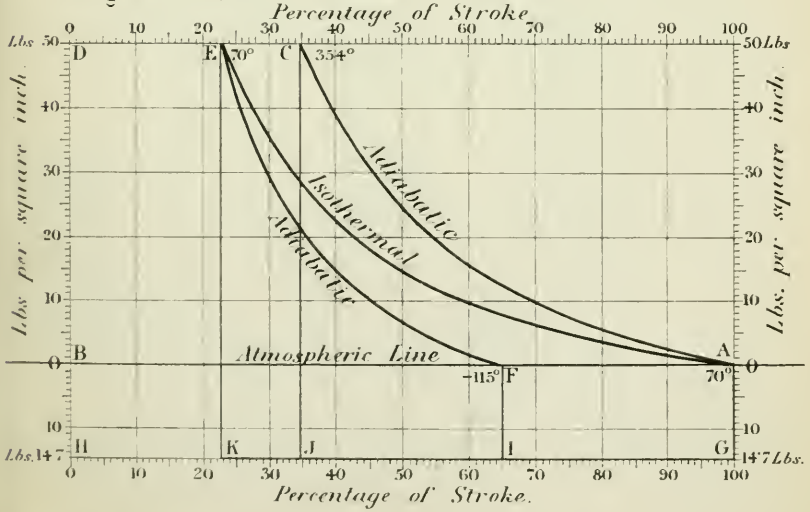


Fig. 2. *Compression and Expansion of Air.*



(Proceedings Inst. M. E. 1886.)

Fig 4.
Compression Machine 1834.

Fig. 3.
Revolving Cylinder.

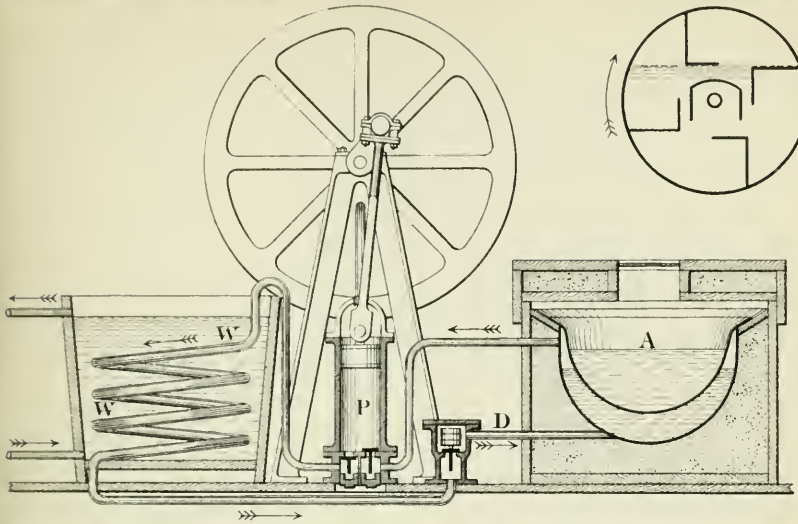
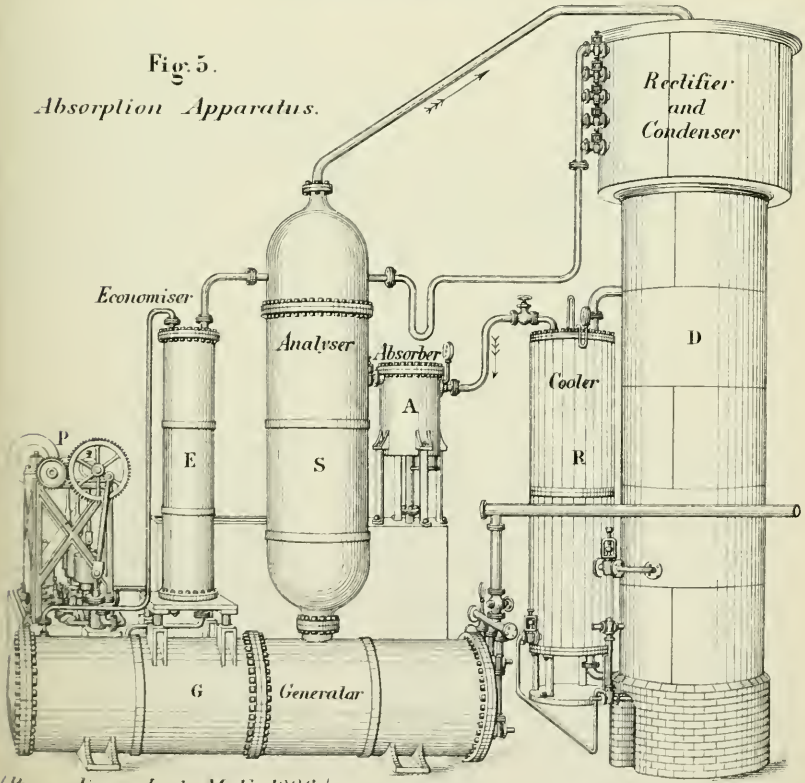


Fig. 5.
Absorption Apparatus.



(Proceedings Inst. M. E. 1886.)

Ether Compression Machine.

Fig. 6. *Elevation*

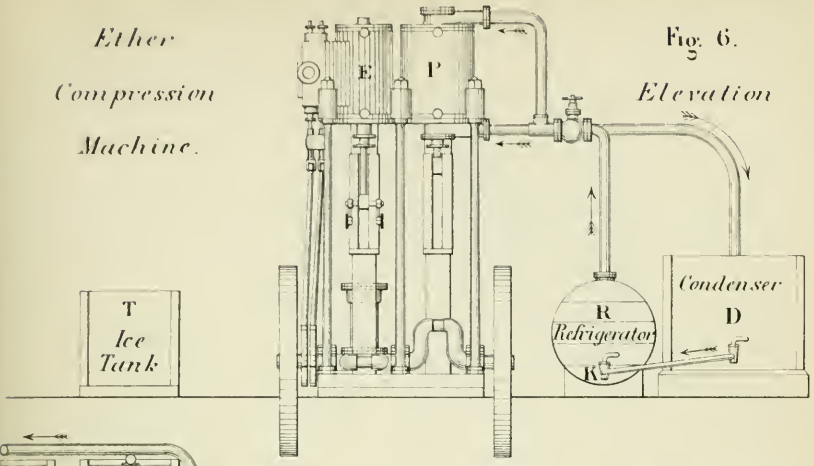
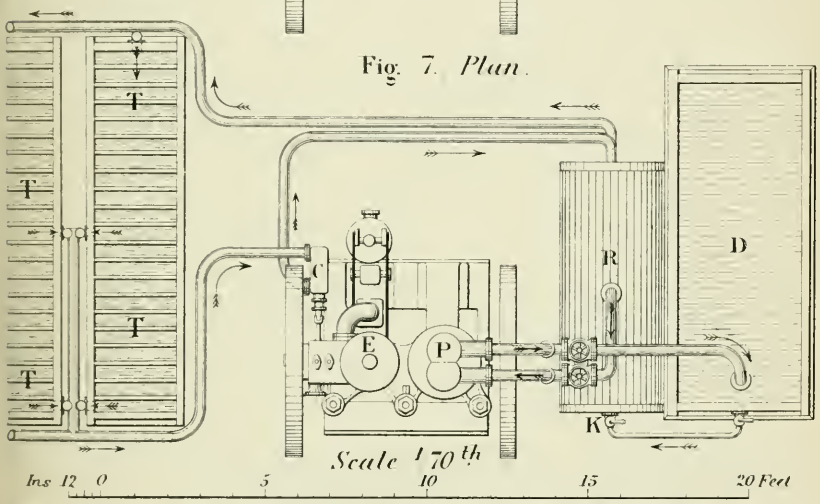


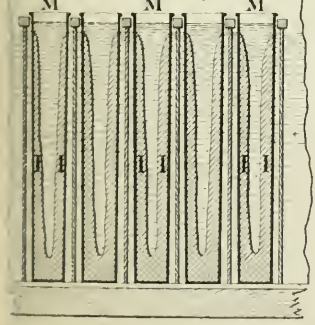
Fig. 7. *Plan.*



Scale 1/70th

Ins 12 0 5 10 15 20 Feet

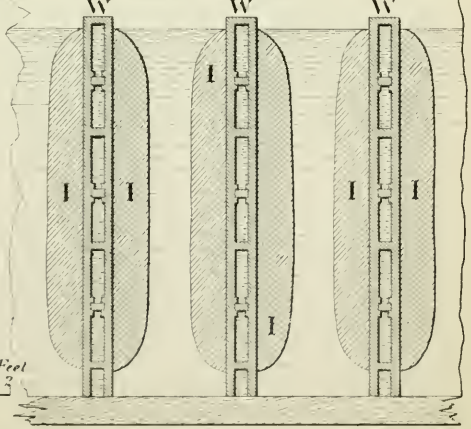
Fig. 8. *Can or Mould System*



Scale 1/20th

Ins. 12 6 0 1

Fig. 9. *Cell System.*



(*Proceedings Inst. M.E. 1886.*)

Ammonia Compression Machine.

Fig. 10. *Elevation.*

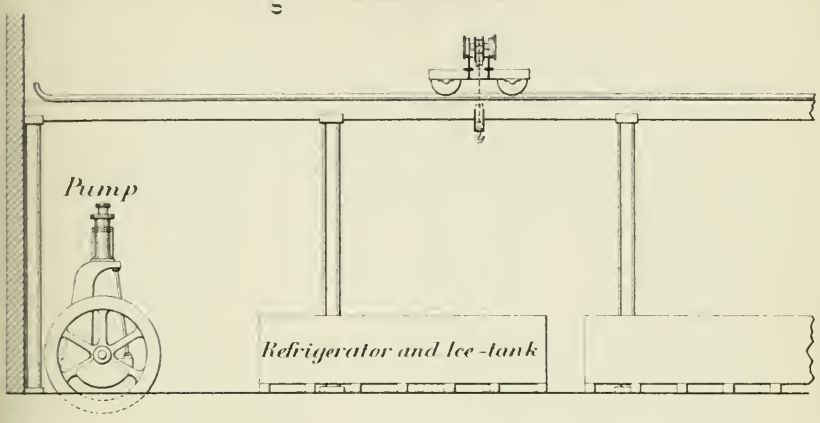
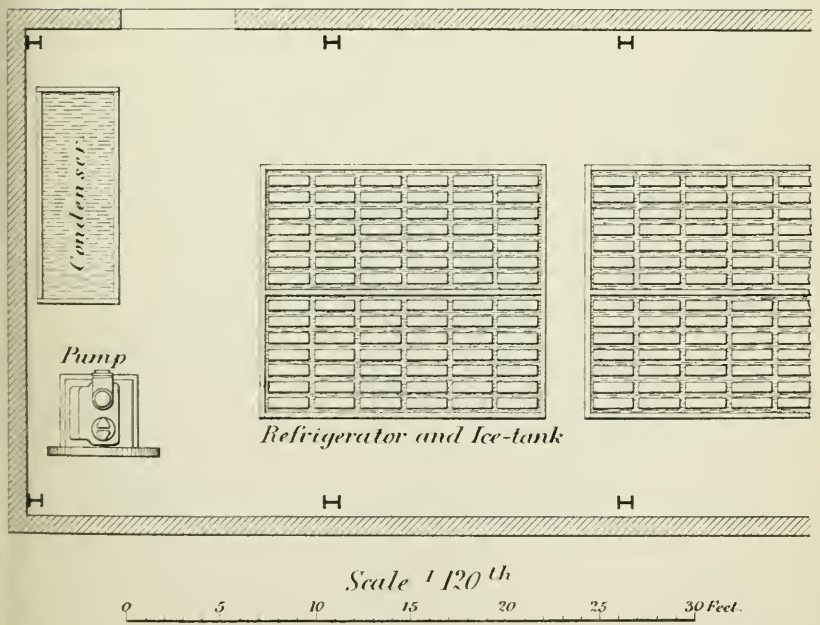


Fig. 11.

Plan.



(Proceedings Inst. M. E. 1886.)

Dry-Air Refrigerator.

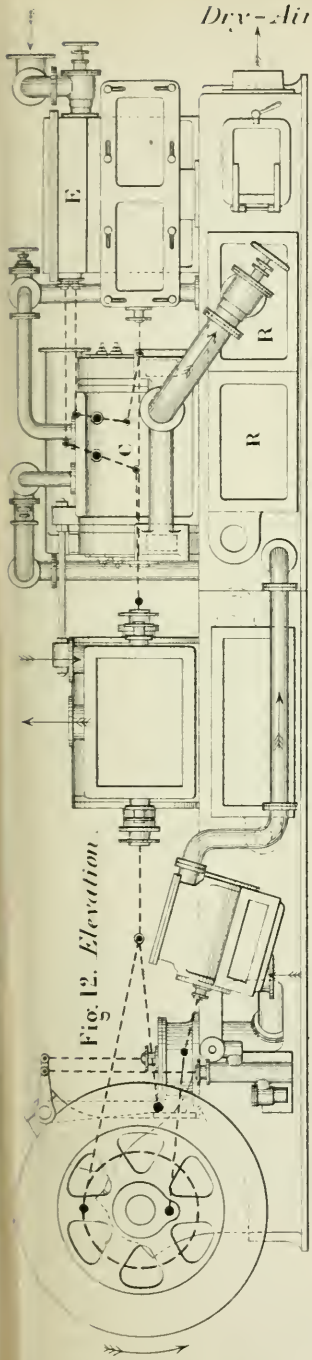


Fig. 12. *Elevation.*

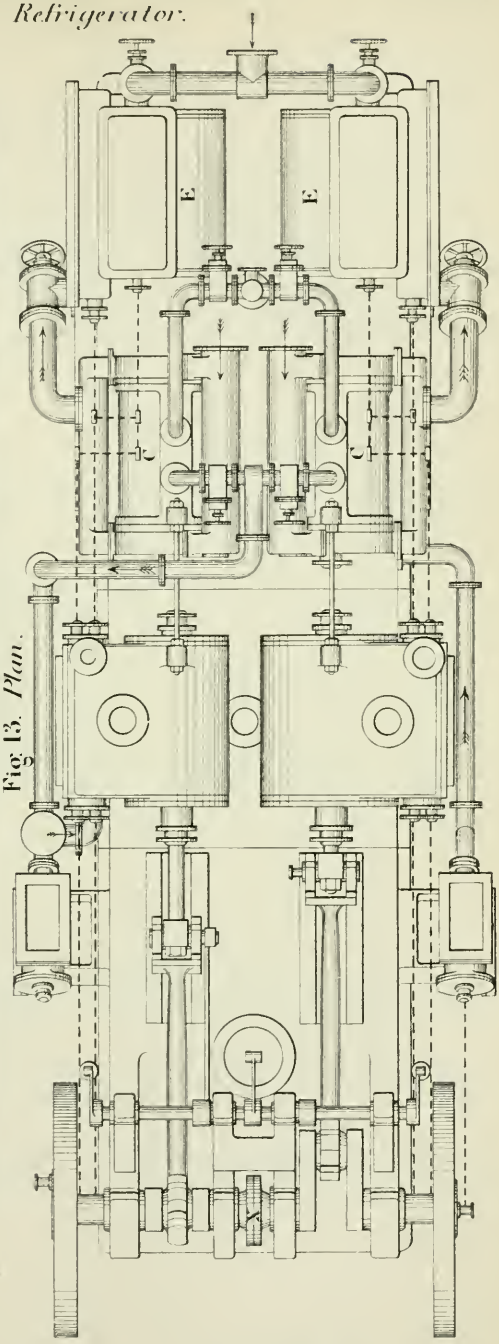


Fig. 13. *Plan.*

Scale $\frac{1}{50}$*th*

(Proceedings Inst. M. E. 1886.)

ns 12 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet

Double-acting horizontal Cold-Air Machine.

Fig 14. *Elevation.*

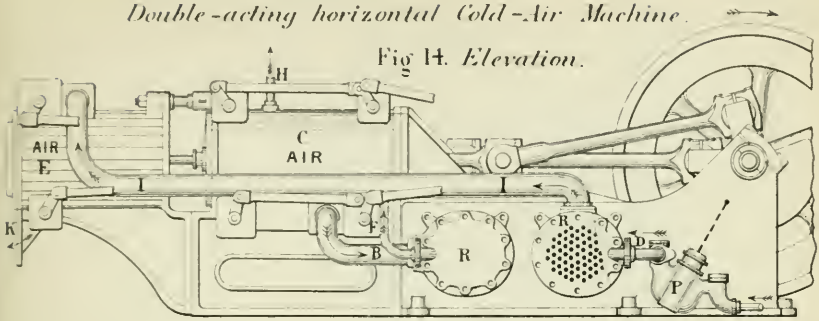


Fig 15. *Plan.*

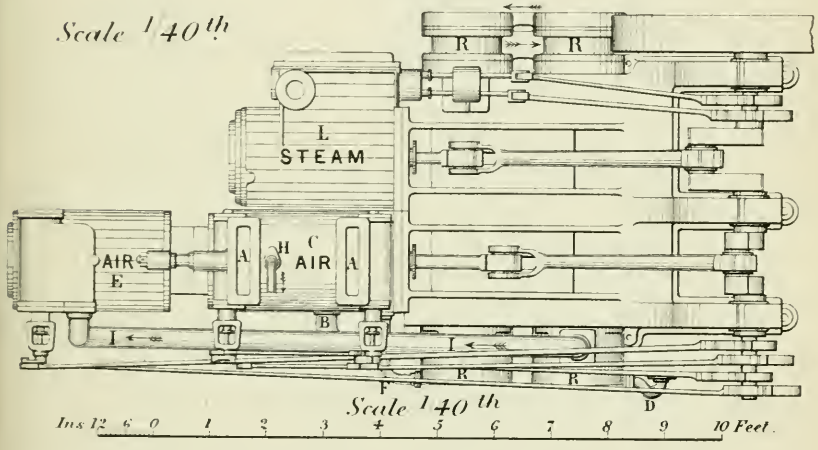
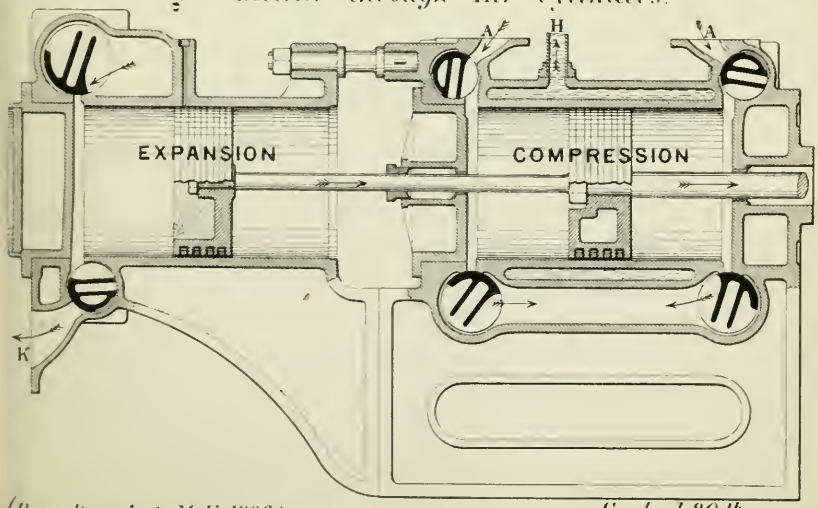


Fig 16. *Section through Air Cylinders.*

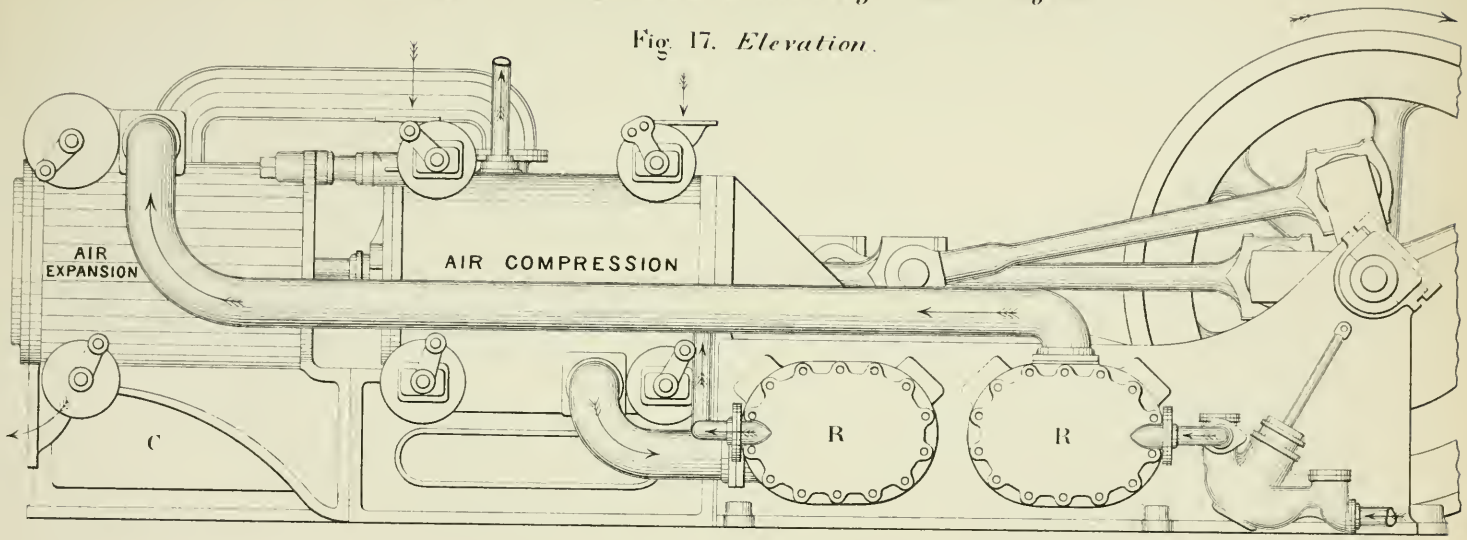


(Proceedings Inst. M. E. 1886) *Scale 1/20th*

REFRIGERATING MACHINERY.

Double-acting horizontal Cold-Air Machine, driven by compound condensing steam-engine.

Fig. 17. *Elevation.*



(Proceedings Inst. M. E. 1886.)

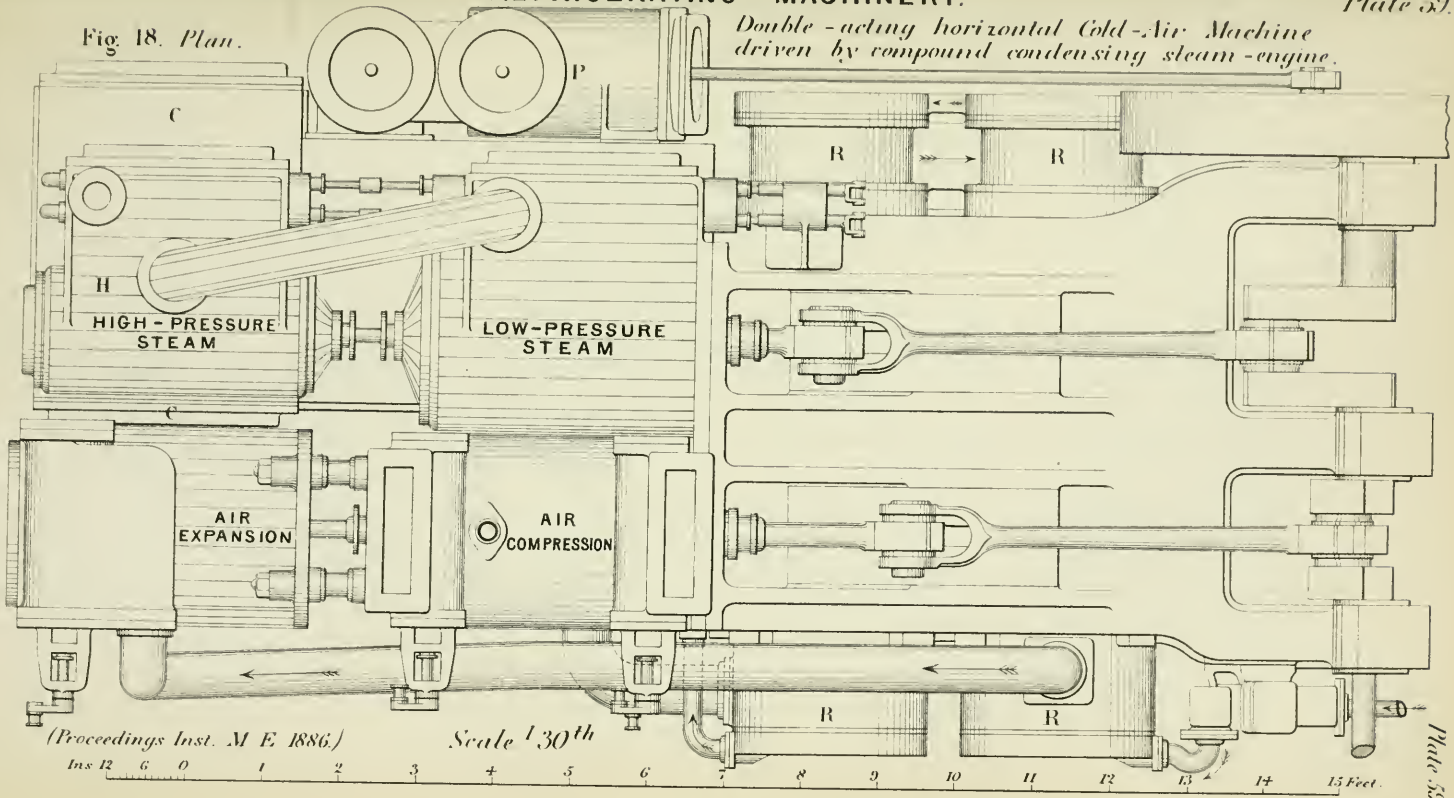
Scale $\frac{1}{30}$th

Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Plate 58.

Fig. 18. *Plan.*

Double-acting horizontal Cold-Air Machine driven by compound condensing steam-engine.



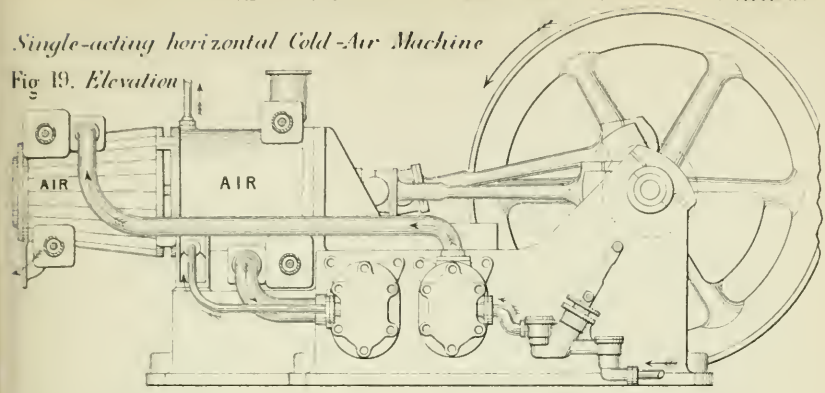
(Proceedings Inst. M E 1886.) *Scale 1/30th*

Ins 12 6 0 1 2 3 4 5 6 7 8 9 10 11 12 13 14 15 Feet.

Plate 59.

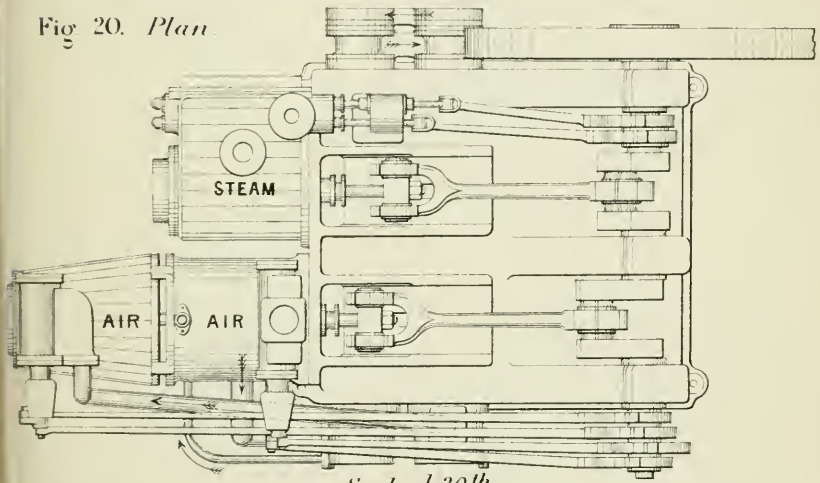
Single-acting horizontal Cold-Air Machine

Fig 19. *Elevation*



Scale 1/30th

Fig 20. *Plan*



Scale 1/30th

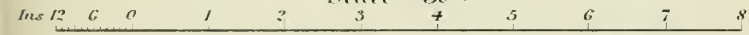
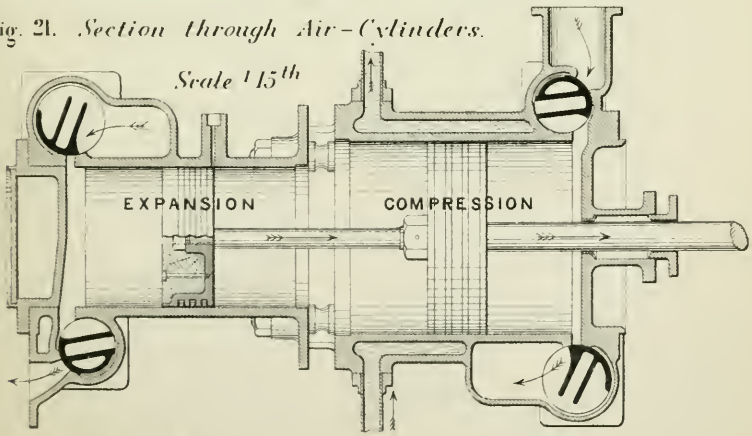


Fig. 21. *Section through Air-Cylinders.*

Scale 1/15th

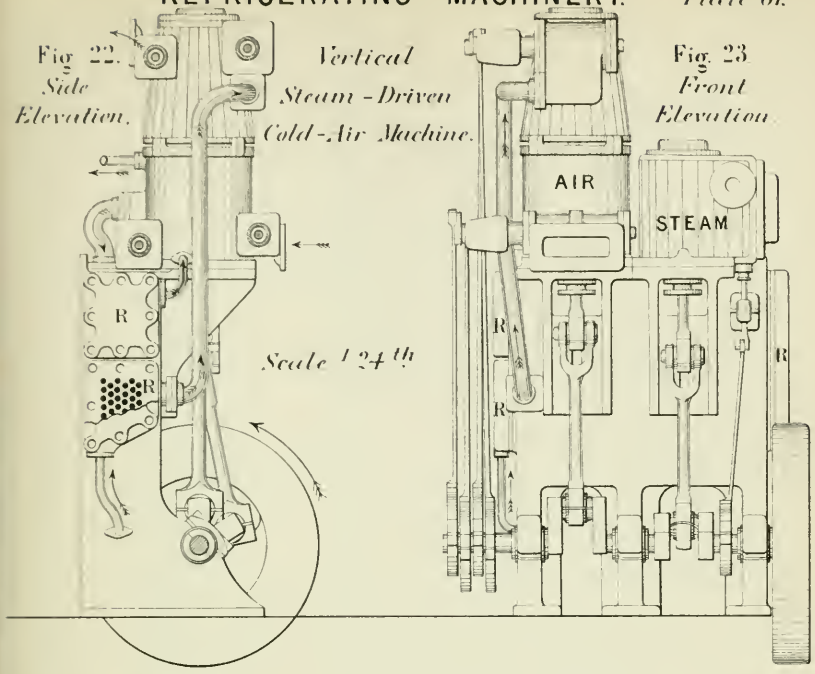


(Proceedings Inst. M. E. 1886)

Fig. 22. *Side Elevation.*

Vertical Steam-Driven Cold-Air Machine.

Fig. 23. *Front Elevation.*

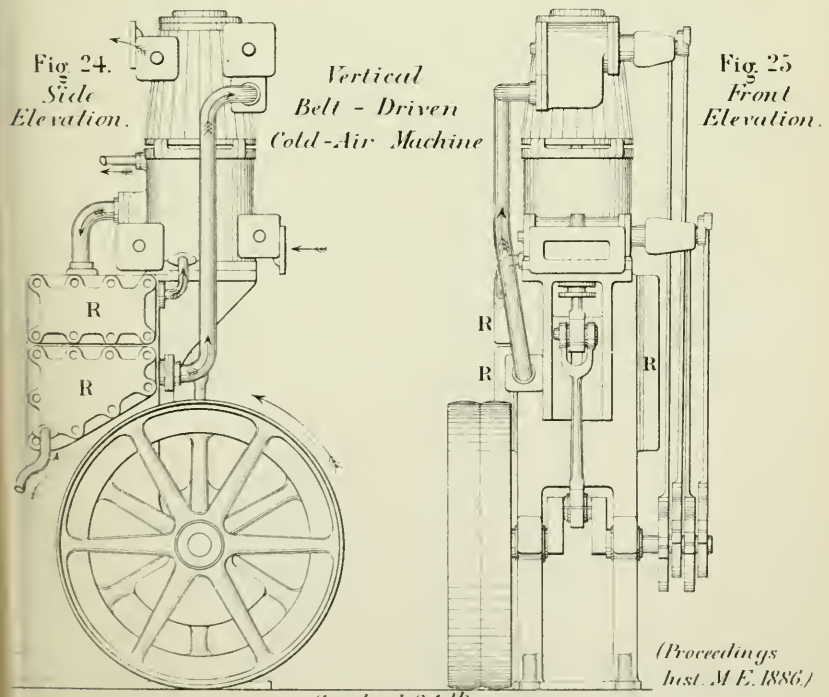


Scale 1/24th

Fig. 24. *Side Elevation.*

Vertical Belt-Driven Cold-Air Machine

Fig. 25 *Front Elevation.*

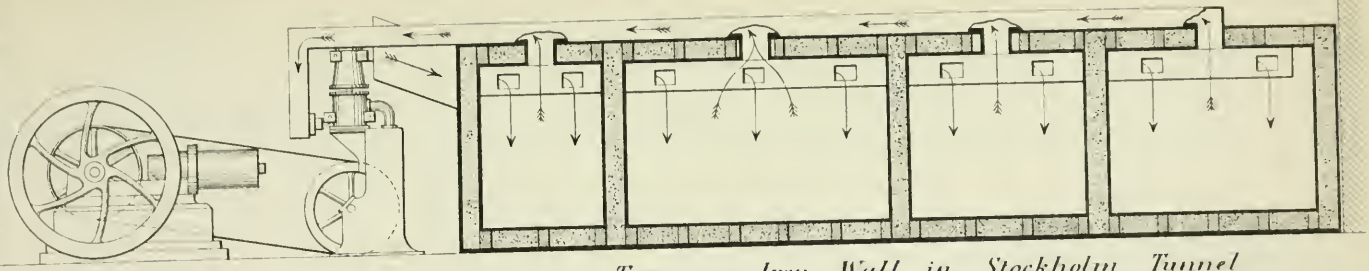


(Proceedings Inst. M.E. 1886.)

Scale 1/24th

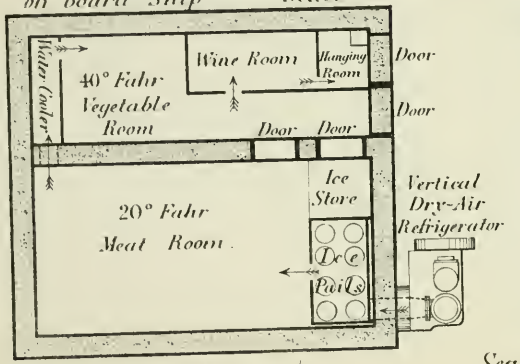
Ins. 12 6 0 1 2 3 4 5 6

Fig. 26. *Section of Cold-Air Store for preserving meat.* Scale 1/100th



Temporary Iron Wall in Stockholm Tunnel

Fig. 27. *Plan of Cold-Air Store on board Ship* Scale 1/100th



(Proceedings Inst. M.E. 1886.)

Fig. 28. Scale 1/100th *Elevation of Wall*

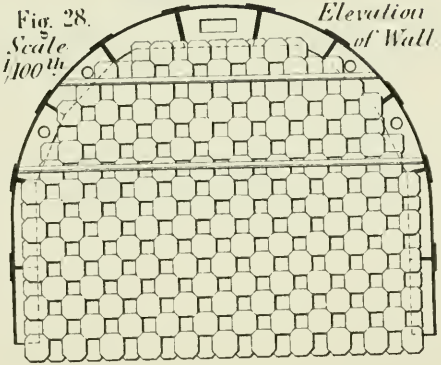
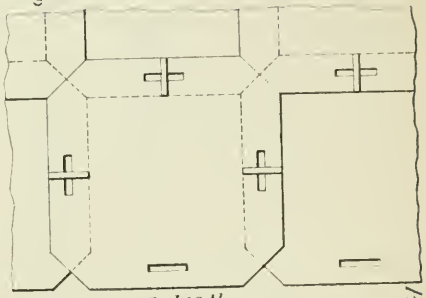


Fig. 29 *Details of plates and bolts.*



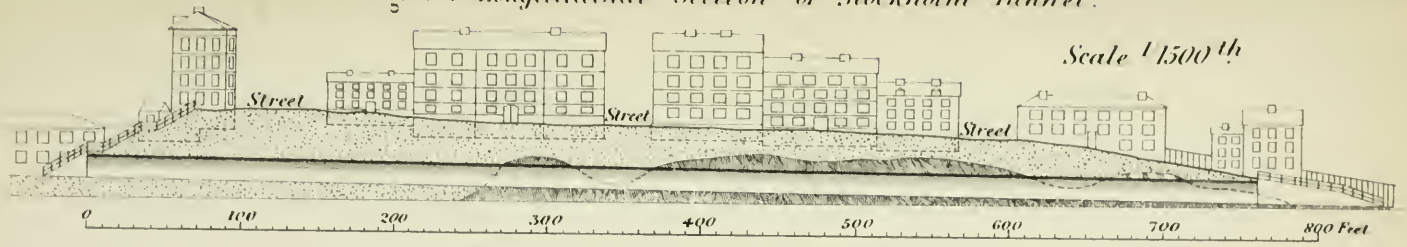
Scale 1/10th

Scale 1/100th

0 5 10 15 20 25 Feet.

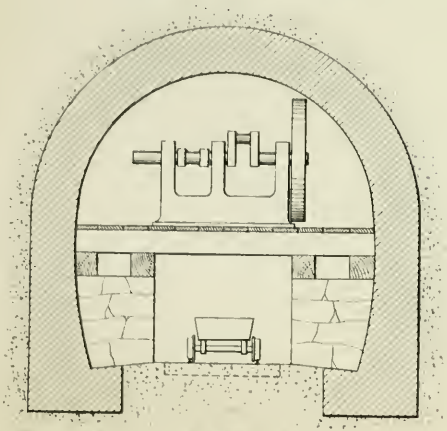
Plate 62.

Fig. 30. *Longitudinal Section of Stockholm Tunnel.*



Freezing Chamber in Tunnel.

Fig. 31. *Cross Section.*



(Proceedings Inst. M. E. 1886.)

Fig. 32. *Longitudinal Section.*

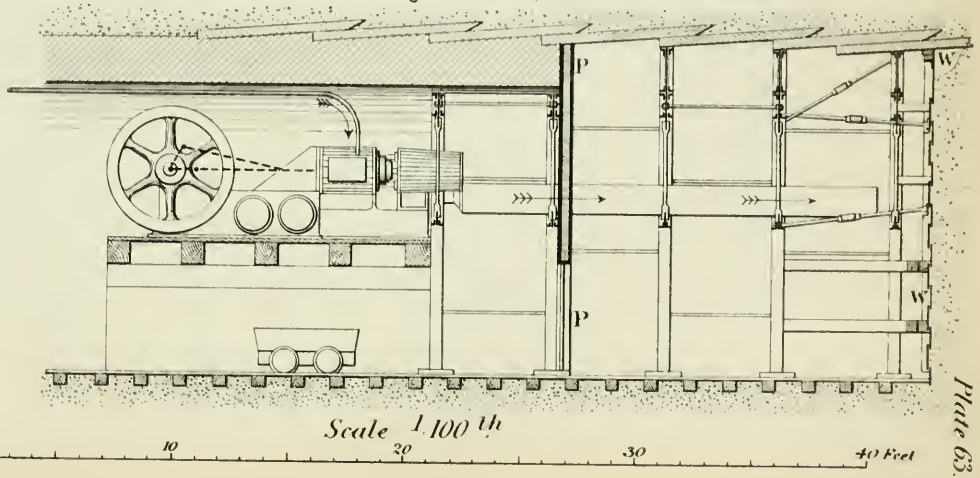


Plate 63.

Institution of Mechanical Engineers.

PROCEEDINGS.

August 1886.

The Summer Meeting of the Institution, commencing on Tuesday, the 17th of August 1886, was held in London. Bearing in mind the cordial reception given to the Members on the occasion of the Summer Meeting in Belgium in 1883, the Council invited the "Société des Ingénieurs sortis de l'Ecole de Liége" to attend and take part in the Proceedings. The Members and the Belgian visitors assembled in the rooms of the Institution of Civil Engineers at Ten o'clock a.m.; Jeremiah Head, Esq., President, in the chair.

The Meeting was opened with the following introductory remarks and welcome by the President:—

Gentlemen,

I need hardly remind you that our Summer Meeting has always been considered the most important of the whole year. It lasts at least twice as long as any other, and, besides the reading and discussion of papers, comprises visits to various works and places of interest to Mechanical Engineers. On the present occasion the place selected has been the Metropolis. Several years have elapsed since our Summer Meeting was held here, and consequently we have not had for a long time an opportunity of visiting the London works, and testing what our London Members and friends could do for our pleasure and instruction. Your Council were therefore delighted to accept the cordial invitation they received from this great city. Through the assiduous labours of a most influential Local Committee, presided over by Mr. G. B. Rennie, supported by Mr. W. Anderson as Vice-Chairman, and with Mr. Henry Chapman as Honorary

(The President.)

Secretary, and all acting in concert with the staff of the Institution, a programme has been prepared which we should indeed be fastidious if we did not heartily appreciate. As you will find every arrangement clearly set forth therein, I need not refer at greater length to that subject, except so far as to point out that you will be afforded an opportunity to visit that marvellous collection of products and manufactures and illustrations of our Indian and Colonial Empire, which now occupies the Exhibition buildings at South Kensington, and which has excited the wonder and admiration of the whole nation.

It is now my pleasant duty to remind you that we have here present to visit us, and to assist in making our Meeting a success, a considerable number of our Belgian brother engineers, who have come in times past from the University of Liége. That institution, if I am rightly informed, was built about fifty years ago. It contains every department and every appliance which such an institution ought to contain. Its operations are carried on by more than fifty professors, and attended by more than a thousand students. But our Belgian friends are entitled to our warmest friendship for other reasons than that they hail from one of the most celebrated universities of Europe. You all remember the pleasant and successful Meeting which our Institution held at Liége three years since. Our friends on that occasion did their utmost to make our visit instructive and pleasant; and we parted from them with the unanimous feeling that, come what would, we must take the first opportunity of receiving them in a similar manner in our own country. That opportunity, postponed for a year or two by insuperable impediments, has now at last arrived. You will, I am sure, heartily support me when on behalf of this Institution I bid them a warm welcome to London and to England; and you will bear with me if I endeavour to emphasize this welcome by saying a few words directly to them in the best French of which, as a most imperfect linguist, I am capable.

CHERS COLLÈGUES ET AMIS DE BELGIQUE,

Nous n'avons pas oublié que quand nos sociétaires visitèrent votre pays, il y a trois ans, plusieurs d'entre vous, avec la courtoisie qui vous est propre, portèrent souvent la parole dans

notre propre langue. Aussi, malgré toute la difficulté qu'un taciturne Teuton peut éprouver à abandonner, même pour un instant, sa langue maternelle, et pour mieux vous montrer combien nous désirons vous accueillir aussi amicalement, s'il est possible, que vous le fîtes vous-mêmes pour nous, j'ai voulu vous souhaiter la bienvenue en vous disant quelques mots en français, persuadé que vous me pardonnerez si je les prononce mal. D'ailleurs, on m'assure, et je crois, qu'il est de mon devoir de donner l'exemple, et de délier les langues de mes compatriotes pour les pousser à parler français avec vous autant qu'il leur sera possible, et rendre ainsi plus intime et plus complète la confraternité Anglo-Belge.

Messieurs, nous sommes on ne peut plus heureux de vous voir ici parmi nous ; et nous vous remercions de n'avoir pas hésité à braver les périls d'un voyage et d'une traversée pour venir nous rendre visite. Nous avons préparé, pour les excursions que nous aurons à faire ensemble, un programme, que nous nous sommes efforcés de rendre aussi intéressant que possible ; et nous ne pouvons que souhaiter qu'il ait votre approbation. S'il vous était utile d'avoir des renseignements plus complets que ceux que nous avons fait imprimer à votre intention, je suis certain que le Secrétaire Honoraire de ce Congrès, M^r^ Henry Chapman, qui lui, au moins, possède complètement la langue française, ou M^r^ Bache, notre secrétaire, qui parle aussi votre langue, seront heureux de vous les donner.

Les Mémoires dont le texte vous a été distribué sont accompagnés d'une traduction, en regard ; et je serai très reconnaissant à chacun de vous de prendre part à la discussion qui suivra leur lecture, en adoptant pour cela la langue qui lui conviendra le mieux.

Encore une fois, et de tout cœur, Messieurs, soyez les bienvenus.

M. Adolph Greiner—Member of Council of the "Société des Ingénieurs sortis de l'Ecole de Liége," representing M. Trasenster, the President—thanked the President for the very warm welcome he had given to the Belgian visitors. They knew that they should not only derive pleasure from the excursions, but that they should also learn many things from the distinguished company whom they

(M. Adolph Greiner.)

were invited to meet. He very much regretted that their able President, M. Trasenster, could not be present with them, as he was unfortunately detained at home by the severe illness of his wife. He had been requested by him to express his heartfelt regret at not being able to attend the meeting. His fellow-countrymen he was sure would return home with the very best impression of this great country. Every time they had come to England they had gone back with new and great ideas; and the same result he was confident would follow from their present visit. He again thanked the President for his kind words of welcome.

The PRESIDENT announced that he had received a letter from the Lord Mayor of London, expressing his lordship's regret that he was unable to be present to welcome the Members of the Institution and the Belgian Engineers. He had unfortunately been obliged to leave town for the country, or he would certainly have attended the meeting.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The PRESIDENT announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following twenty-four candidates were found to be duly elected:—

MEMBERS.

MATTHEW WHELDON AISBITT,	Cardiff.
WILLIAM BAILEY,	London.
THOMAS BUCKNEY,	London.
THOMAS CRYER,	Manchester.
FRANCIS JOSEPH EDE,	Cachar, India.
FREDERICK FOSTER,	London.
ARTHUR ROBERT WILLIAM FULTON,	Wellington, N.Z.
WILLIAM JAMES HALL,	Limerick.
HENRY WILLIAM JEWELL,	Winchester.

Charles Albert Knight,	Glasgow.
Charles Eyre Lee,	London.
John Edward Livsey,	London.
Alexander Scott MacLean,	Greenock.
John Smith Miller,	Nottingham.
Percy John Ogle,	London.
Thomas Henry Owen,	Cardiff.
Robert Barlow Seddon,	Wigan.
Henry Tipping,	London.
Henry Robinson Towne,	Stamford, U.S.
Robert Weatherburn,	London.

ASSOCIATES.

William Clyburn Bennison,	Sheffield.
William J. P. Peacock,	London.

GRADUATES.

Charles Carver,	Nottingham.
Sidney Ward Conyers,	Sydney, N.S.W.

The President reminded the meeting that, in accordance with the announcement already made to the Members by circular, it was now their duty to appoint a Treasurer in succession to the late Mr. Thomas Druitt, whose decease he was sorry to say had occurred since the last meeting. Bye-Law No. 19 directed that—"the Treasurer shall be a Banker, and shall hold the uninvested funds of the Institution, except the moneys in the hands of the Secretary for current expenses. He shall be appointed by the Members at a General or Special Meeting, and shall hold office at the pleasure of the Council." He therefore invited any Member now to propose a successor to the late Mr. Druitt.

Mr. L. Sterne expressed his regret that they had lost their late Treasurer; they had met him both professionally and socially, and whenever they came in contact with him he always received them with great courtesy. His successor in the management of the

(Mr. L. Sterne.)

Union Bank of London, Charing Cross, was a gentleman whose ability and amiability would ensure the same treatment of the Members and of the Institution accounts in the future as had been met with from Mr. Druitt in the past. He had therefore much pleasure in proposing "That Mr. Harry Lee Millar, having succeeded the late Treasurer, Mr. Druitt, as manager of the Union Bank of London, Charing Cross Branch, where the Institution account is kept, be appointed by the Members of the Institution to succeed him as Treasurer of the Institution of Mechanical Engineers."

Mr. John R. Ravenhill seconded the motion.

The President asked if there was any other nomination.

No one else being nominated, the motion was put to the meeting, and carried unanimously.

The President then delivered his Address: after which the following Paper was read and partly discussed:—

Experiments on the Steam-Jacketing and Compounding of Locomotives in Russia; by Mr. Alexander Borodin, Engineer-in-Chief of the Russian South Western Railways, Kieff.

At a quarter before One o'clock the Meeting was adjourned to the following morning.

The Adjourned Meeting was held in the rooms of the Institution of Civil Engineers, London, on Wednesday, the 18th of August 1886, at Half-past Nine o'clock, a.m.; Jeremiah Head, Esq., President, in the chair.

The following Paper was read and discussed:—

On the Working of Compound Locomotives in India; by Mr. Charles Sandiford, Locomotive and Carriage Superintendent of the North Western Railway, Lahore.

The discussion upon Mr. Borodin's Paper being continued jointly with that on Mr. Sandiford's throughout the whole morning, the three remaining Papers announced for reading and discussion were adjourned to subsequent meetings.

The President proposed the following Votes of Thanks, which were passed by acclamation:—

To the Institution of Civil Engineers for their kindness in granting the use of their rooms for the occasion of this Meeting.

To the Local Executive Committee—especially to the Chairman, Mr. Rennie, to the Vice-Chairman, Mr. Anderson, and to the Honorary Secretary, Mr. Henry Chapman—for the excellent arrangements made by them to ensure the success of the present Meeting, and for the cordial and hospitable welcome prepared for the Members and Visitors in London and in the Excursions.

To the Proprietors of the various Works and other Establishments to which visits have been freely invited; and to the Directors of the Gas Light and Coke Company for their hospitable invitation in connection with the excursion to their Works.

The Meeting then terminated. The attendance was 331 Members and 166 Visitors, of whom 93 were Belgian Engineers.

For the week following the Meeting, the five undermentioned provincial Excursions were arranged for the Belgian Engineers. By Members and their friends in the several districts elaborate arrangements were made for the handsome and hospitable reception and entertainment of the visitors.

To Crewe and Liverpool, including a special trip to the Vyrnwy Water Works of the Liverpool Corporation; also to Wigan and Barrow-in-Furness, and to Blackpool.

To Glasgow, Edinburgh, and the Forth Bridge.

To Middlesbrough, Darlington, and Newcastle-on-Tyne.

To Derby, Burton, and Birmingham.

To Swansea, Cardiff, and the Severn Tunnel.

ADDRESS OF THE PRESIDENT,

JEREMIAH HEAD, Esq.

At the Summer Meeting next after the installation of a new President, it has always been customary in this Institution that he should deliver an inaugural address of some length. But at the meeting occurring a year later, you have usually been kind enough, in case of his re-election, to expect from him only one of a much less formidable character. Desiring to keep to the safe course of acting as nearly as possible according to established precedents, I propose now to submit to you a very few imperfect observations on a subject which interests me; and I hope in so doing I shall succeed in also interesting you, and shall not exhaust your patience.

The Presidential Addresses which have been given during the last two or three years before this and kindred Institutions, have almost invariably contained some allusion to the terrible depression through which the trade of this and other countries has been passing. Inasmuch as this is a matter which deeply concerns mechanical engineers, and has long been almost uppermost in the minds of many of them, I propose to make a few remarks upon it, in the hope that I may perchance be able to add one little spark to the great flood of light, for which by common consent there seems to be so urgent a necessity.

The term "Depression of Trade" has unfortunately become "as familiar in our mouths as household words." A Royal Commission was appointed just a year ago to investigate and find out all about it. Four big volumes of evidence have already been published. The causes and remedies, suggested by the witnesses, are numerous and various enough to bewilder the clearest brain; whilst the members of the Commission have up to the time of writing this address prudently

refrained from expressing themselves in any decided or conclusive manner.

One thing seems very certain; and that is that mechanical engineers have had not a little to do with bringing about the present state of things. Dr. Percy, the able and highly esteemed President of the Iron and Steel Institute, referred pointedly to this matter in the brief address he gave at Glasgow last autumn.* He took as his text a circumstance of which he had been informed by Sir Joseph Whitworth, which was to the effect that a first-rate Nottingham lace-machine now produces as much work as 8000 women could do formerly.† He went on to show how enormously the power of production has increased, as regards pig and manufactured iron, steel, ship-building, and also the metals copper, silver, and lead; and that in every case there has also been a continuous and heavy fall of prices. Dr. Percy attributed the depression of trade to "over-production." He said, as the conclusion at which he had arrived, that either consumption must be increased, or production must be limited; and as regards iron and steel he left it to the iron and steel masters, that is to the producers, to say which of the two courses they would adopt.

It may fairly be questioned whether giving the name "over-production," as the cause of the commercial disease from which we have been suffering, really brings us any nearer to the cure. There would seem to be indeed only three conditions which ever can, or ever could, determine the direction and speed of variations in market prices. These conditions are:—1st, "over-production," which occasions falling prices; 2nd, what may be termed "balanced-production," which results in steady prices; and 3rd, "under-production," which leads to rising prices.

The terms over-production, balanced-production, and under-production are obviously relative ones. They may be used in reference to the rate of *consumption* going on at the time being. Or they may be used in reference to the rate of *production* at some

* Journal of the Iron and Steel Institute, No. II., 1885, p. 372.

† Proceedings of the Institution of Mechanical Engineers, 1856, p. 130.

preceding time. In the former case, over-production and under-consumption mean the same thing. In the latter case, and I imagine this is the sense intended by Dr. Percy, there is obviously no use in limiting production to an antecedent standard, unless the diminished rate of consumption be also raised to a corresponding standard, or higher, so as to produce steady or rising prices.

The chief difficulty in the way of any proposal to augment consumption, or to limit production, appears to be, that the first remedy has so far been found impracticable; and the second has generally proved unsuccessful after a time, whenever artificially attempted. The collapse of the International Railmakers' Association is one of the most recent of a great many instances.

When limitation of production comes about through producers suspending operations because some of them find it their interest and others are compelled by circumstances to do so, then the limitation of production which ensues may be said to be due to natural rather than to artificial causes; and this must always be the ultimate result of over-production.

To show that over-production is no new phenomenon, but merely the recurrence of an old and familiar one, is not by any means to deny its reality at the present time or its disastrous effect upon producers.

We mechanical engineers have done our utmost to make possible what has actually happened, and indeed that is the very *raison d'être* of most of us. Besides the enormously increased facilities for over-production in lace, in the metal trades, and in ship-building, the same thing has occurred in very many if not in all other trades and manufactures. In the special excursions which the members of our Institution have made during the last two or three years, to works in various parts of the country, the ever-increasing facilities for producing cheaply articles of utility, by means of improved mechanism and improved arrangements, have always been the chief objects of attraction to us. In admiring them we thought we were admiring what would tend to increase the comfort and prosperity of every one; and it never occurred to us that we were encouraging an unsound

principle, or that we were using our influence in the direction of depression of trade and wide-spread misery.

Recalling some of our visits to works in backward order from the present time, we come first to the Coventry Cycle Works, where we noticed the extended use of stamping machinery, which produced with great rapidity the most difficult steel forgings in an almost finished state and at a very slight cost. Coventry manufacturers do not however appear to have attained perfection in the production of every detail of their work. For we learned that a well-known firm of manufacturers in Essex was able to supply the small bolts and screws used in cycles better and cheaper than they could be produced on the spot, notwithstanding the extra carriage of material to, and of the finished article from, the place of manufacture. This result was said to be due to the employment of highly efficient machinery and cheap agricultural labour, the adoption to the utmost of the piece-work principle, and the concentration in one factory of orders from many cycle makers.

At the Lincolnshire and Nottinghamshire Agricultural Machinery Works we last summer likewise noticed the extended use of stamping machinery, hydraulic flanging and riveting, of multiple punching and drilling, of milling tools, and of manifold wood-working machinery, sawing, planing, shaping and boring the various pieces of wood, so as to require hardly anything but putting together.

The advantages of adhesion to a few types, and to but a few sizes of each type, of working to gauges throughout, of the piece-work system, of making for stock as regards all details, and taking from stock when erecting, so as to avoid delays, impressed themselves strongly upon us; and we realised what rapid strides had been made in those places in the direction of increased production at diminished cost. At the Great Northern Railway Locomotive shops at Doncaster, and at the Midland Railway shops at Derby which we visited the previous autumn, we saw similar improvements in full operation, as regards locomotives and railway carriages. Two years before, many of us visited the ready-made clothing and boot and shoe factories at Leeds, and there noticed what great progress had been made in the multiplication and cheapening of these articles of every-day use, by means of the

introduction of the band-saw, the sewing machine, and the adoption of piece-work and the factory system generally.

Reverting for a moment to our Lincoln visit, what shall we say of the steam-navvy which has been so ably developed by Messrs. Ruston Proctor and Co.?* Each one of these powerful machines is capable of doing the work of from 80 to 120 human navvies, according to the nature of the soil to be dealt with; and presumably, alas! of turning them into the ranks of the unemployed. In the course of our visits to works during the present meeting, we shall have many further opportunities of observing how machinery has been brought to bear, not only in making articles with less labour than formerly, but also in manufacturing what would otherwise be beyond the powers of humanity to produce at all. This will be specially observable at the gun-factory at Woolwich, and at the small-arms factory at Enfield.

But whilst we mechanical engineers have everywhere been guilty of the sin, if it be a sin, of aiding and abetting over-production, and thus preparing, as it were, a rod for our own backs, we seem in some things to have been strangely surpassed by foreigners. In such cases we are sharing to the full the punishment, without the satisfaction of having partaken in the antecedent gains. Among the few manufactured articles imported largely into this country are clocks and watches. Thirty years ago, a good ordinary silver watch of English make cost £6. Within ten years an equally serviceable silver watch began to be sold by the American Waltham Watch Co. for under £3. Mr. T. R. Russell, a representative watchmaker from Liverpool, who contributed to the Depression of Trade Commission† a statement as regards his trade, says that watchmaking was formerly of special importance in Liverpool. About 1800 operatives were then employed; now there are not 200! The bulk of the operatives before dying suffered greatly, and sank in the social scale. Thirty years ago, four-fifths of the large number

* See Mr. Ruston's paper read at the Lincoln meeting, August 1885, p. 349.

† First Report of the Royal Commission on Depression of Trade and Industry, p. 95.

of watches made in Liverpool were exported to the United States. This trade was entirely killed by the increased American tariff, while the home market is now flooded with American and Swiss surplus stocks. This does not matter much to large dealers like Mr. Russell, but he considers it very cruel to the English workmen. He believes that the watch trade in Coventry and in London is a dying industry!

Now if the Americans prevented us, years ago, from sending our watches to them, by imposing a high import tariff, that was our misfortune, and not our fault. But if with dearer material and dearer labour, and notwithstanding the cost of transit, they can now sell watches in the very heart of England at a lower price than we can produce them for, this must be our fault as well as our misfortune. It would seem a case of over-production by foreigners, leading to under-production by ourselves. The Americans appear to have anticipated us in the adoption of various expedients, equally open to ourselves. The Waltham Watch Co. is one of comparatively recent origin. The managers began by studying the watch as a piece of mechanism. They selected the best points from every current type, and added some improvements of their own. They found they might safely abandon the complication caused by the fusee and chain, if for the ordinary main-spring they substituted one of gradually increasing section, so that it should exert the same force or nearly so, when almost unwound, as when fully wound up. Having settled on a standard type, they determined to adhere to it, and to make certain sizes in it, and no others. They then at infinite pains devised or procured the beautiful machinery of which we saw samples at the "Inventories" last year, for making every part in every size. They adopted the plan of having a gigantic factory, with all the benefits of system and concentration, instead of the old English method under which workmen made the different parts in their own houses, with less machinery, and under circumstances of an altogether less favourable kind. We might have done all this as well as the Americans, but we did not, or at all events not until we had lost much of our trade. We clung to our own old modes and methods, after better ones had been discovered. Everyone knows what an

infinite number of sizes and types of English watches there are. Diffusion instead of concentration, adherence to old habits instead of quick appreciation of new and better ones—these are probably the causes which, if Mr. Russell's evidence be correct, have made British watch-making now "a dying industry." *

But Americans have not been allowed to have it all their own way. The Swiss have long worked on nearly the same system, and they have the advantage of cheaper labour. Formerly their watches were not thought much of in this country because they were of too flimsy a type and character. Latterly they seem to have improved in this respect, or at all events they have studied the requirements of the market, and adapted themselves to it. The price at which they are now producing watches is something marvellous. I recently bought for a schoolboy a substantial new silver watch in a highly finished case, guaranteed to contain 80 per cent. of metallic silver. The escapement was of the Geneva pattern, the works were electro-gilt, and looked as good as those of any other ordinary watch, and there was a seconds hand, as well as the hour and minute hands. I received a written guarantee under which the seller agreed to do all repairs gratis, which might be required within two years, excluding foul play. I wore the watch myself for a fortnight, and during that time it neither gained nor lost a minute; and the total cost was only 18*s.* 6*d.*! Surely we are approaching the time when it will be cheaper to buy a new watch than have an old one repaired, and when cases of robbing from the person will be seldom heard of, because watches are no longer worth stealing!

Some sensation was recently caused by the announcement that an American firm of bridge builders had tendered successfully for a large bridge for Australia, against English competition, although the advisers of the purchasing colony were English engineers. It appears that the latter had deviated from the ordinary practice of making designs and inviting tenders for the execution of the work. They had in this case permitted contractors to tender on their own

* See the paper on "The Mechanical Art of American Watch-making" read before the Society of Arts, 19 May 1886, by Dr. Leonard Waldo of the Yale Observatory, New Haven, U.S.A.

designs. It was under these circumstances that the American firm obtained the contract, after one of their principals had visited the spot and formed his estimate of the cost and risk. Having secured the contract, they sublet a portion of the work in England and another portion in Scotland, thereby obtaining the benefit of more direct and cheaper transit, and cheaper labour and material. Other portions of the structure, for the manufacture of which the contracting firm have special appliances, will be made by them in America, from British material. The ingenuity of bringing to bear in a single undertaking the talent and resources of several countries in this way must command our admiration. But the lowness of price which resulted in success was no doubt largely due to this particular firm of contractors being allowed to tender to a design in the execution of which they had great experience and special facilities. As in the case of watch-making, it is impossible for a manufacturer to produce at his lowest cost for a customer who insists on a special design, made without the same regard to convenience of execution which the manufacturer would keep in view if the design were his own. Had the usual course been here adopted, it would almost certainly have excluded the most favourable tender.

It may be objected that the tendency of my remarks so far has been rather towards encouragement of over-production than otherwise; whilst many great authorities say that over-production is an evil, and ought to be stopped, unless and until consumption can be proportionately increased. Nothing however would seem to be more difficult than to make the world consume more than it is inclined to consume at any particular epoch. Trade may, of late, have been diverted occasionally from one producer to another; but there is no general benefit in that. The advantage to one has been the loss to another, which is a very different thing from a general increase of demand, benefiting all. Besides, the gainer in such cases of diverted trade has as a rule been the most zealous over-producer, and the careful under-producer has been the loser.

Throughout the whole world, trade seems to have fallen off, notwithstanding the most energetic attempts to prevent it from

doing so. Every country has also been strenuously endeavouring to curtail its purchases from other countries, and supply all its needs from within its own borders. Not only so, but nations have not infrequently become competitors in neutral markets when they have ceased to be customers. Germany in respect of the steel-rail trade,* and France in respect of the shipping trade, are instances of this. Their apparent object in pursuing such a policy, for it is carried out only by an increase of general taxation, is to maintain a larger population than would otherwise be possible. We attempt the same thing in a more direct fashion by means of our poor law; and which of the two systems is most objectionable it is impossible to say. Inasmuch then as artificial attempts to limit production, or to increase consumption beyond the world's demands for the time being, have seldom if ever proved really successful, it would seem as though the Darwinian law of the survival of the fittest still held undisputed sway over the destinies of producers.

It must be manifest to every one, and especially to mechanical engineers, that there may be a great difference in the effect on the future of our national industry, between one and another of the various commodities we send abroad. Some of these commodities may, in their production and sale, beneficially affect us now, and may also bring other benefits in the future. Others may be profitable enough for the time being, but may tend to destroy future trade.

For example, the export of agricultural machinery would seem to belong to the first order. Its production tends to maintain our population, and enrich our manufacturers; and when it arrives at its destination abroad, it helps to make plentiful and cheap the agricultural produce which we want to buy. The same may be said of clothing, which is so largely exported from Leeds and elsewhere to South America and the colonies. By clothing themselves more cheaply than they otherwise could, the inhabitants of these countries

* Second Report of the Royal Commission on Depression of Trade and Industry, page 49, sections 2066–68 and 2081–82.

are enabled to save, and to employ their savings in raising more wool, hides, meat, &c.; and these commodities we are glad to purchase from them.

To make and sell vessels for river and coasting service abroad would no doubt be similarly beneficial to us; for such things, by increasing traffic, enrich the customer country, and increase the chance of further business with us. But to sell to foreigners ocean-going vessels, intended to compete with us for ocean traffic hitherto in our hands, would seem to be of very doubtful advantage. This is especially the case where such a system prevails as the French shipping bounty, whereby French ship-owners are subsidised at the expense of French tax-payers, in order to give them an advantage over all others in competing for the maritime carrying trade of the world.

It has often been doubted, whether from a national point of view it is wise to export coal as largely as we do, and especially at prices which, if we are to believe what we are told, leave no profit to the coal-owner. Coal is an exceptional commodity, in that upon its plentifulness and cheapness so much of our future prosperity as a manufacturing and commercial nation seems to depend. It is not as though the supply were practically inexhaustible, as is said to be the case with respect to the petroleum fields of Southern Russia. Our coal supply is well known to be very limited, at all events as regards the better and more accessible seams. Nevertheless we continue to send it away at the rate of 20 million tons per annum, which is equivalent to 12½ per cent. of the entire production of the United Kingdom.* The only classes who at present prices seem to be in any way benefited by this enormous outpouring of the mineral wealth of the country are the colliers and the royalty owners. We have not even always the advantage of employing our own ships and our own sailors to take it away; for recent statistical returns show that this trade is increasingly done by foreign ships with foreign crews.

* The average exports for the years 1880–84 inclusive were 20,120,000 tons per annum. The average production for the same years was 156,000,000 tons. See Board of Trade returns.

Many of our ablest members have always been occupied in devising and manufacturing machines for factories, and tools for engineering shops. They are ever endeavouring to improve existing types, and to make new ones of still more efficient kinds. But for these gentlemen, we should not have been able to over-produce to anything like the extent we have done, and we should perhaps have avoided the troubles we have thereby got into. Possibly we, in England, might have had the privilege of over-producing all to ourselves—a most advantageous position for us—had not our machine and tool makers always had the habit of exporting to our foreign competitors the same beautiful contrivances which they have sold to their neighbours at home. In every European country, and even on the American continent, English machines and tools of the very best types are to be seen in the principal factories. And when manned as they always are, in European countries at all events, by very much cheaper labour than ours, and working longer hours, they most effectually extinguish any chance there might previously have existed of our supplying the specialities which they produce. At Gratz in Austria, three or four years since, I was shown over a very large and complete boot and shoe factory, furnished with English and American machinery, and attended by cheap female labour. We should obviously have no chance of supplying Austria with boots and shoes after that.

Quite recently large iron and steel works have been erected in the north of Spain, the machinery being devised and manufactured in England on better and more modern methods than the average of those at work in this country. These works are also to some extent superintended by English engineers. The result became impressively apparent when Spanish hæmatite pig-iron was lately offered to Birmingham consumers in competition with that produced in our own large iron centres.*

But we even go further than this. English engineers have repeatedly accepted offers from foreign governments to put up

* Second Report of the Royal Commission on Depression of Trade and Industry, page 47, section 2022.

engineering works in other countries, for the construction of ships and engines; and if I am not misinformed, Belgian engineers have done the same. In these cases capital, organisation, superintendence, and instruction are freely found for the express purpose of establishing industries, which will eventually enable the recipients to do without their teachers, and perhaps to compete with them.

Although in the main our countrymen have in the past been the teachers of foreigners, as regards mechanical science, there are many striking cases where we have been glad enough humbly to learn from them. A recent instance is that of the process of gradual reduction of grain, through fluted chilled rollers, known as the Hungarian process of milling. This beautiful system has now superseded almost entirely the use of mill-stones. The flour made by it was so much superior to that made by the old process, that it at once commanded a preference in the market, and was largely imported. When the cause of the superiority was known, our large corn-millers began to take out their old machinery, and put in new obtained from Hungary. Managers and foremen also came over to instruct them in the use of it. Many of our members will remember seeing at Grimsby, last summer, a large quantity of this machinery *en route* for our corn mills. The Hungarians could not, or at all events did not, refuse to teach us to compete with them. Now English millers can make flour equal to the Hungarian, and English mechanical engineers can supply all the machinery necessary to produce it.

The question here suggests itself, whether either the government of a country, or the manufacturers or exporters thereof, can or ought to exercise any sort of discretion as to the commodities or kinds of machinery or appliances which they sell abroad, having in view the effect of those exports on future trade and commerce. Or should they, as heretofore, be always prepared to supply what anyone from anywhere requires, provided he pays for it?

Whatever our theoretical ideas may be, we shall no doubt have to act on practical lines. The only circumstances under which governments have been accustomed to interfere are when war prevails, and the only exports then dealt with are munitions of war. Even

then, notwithstanding the primary law of self-preservation as a motive and all the armaments of a nation as the prohibiting force, it has seldom been found possible to keep would-be sellers from would-be buyers. It is therefore not in the least likely that the equalisation of technical knowledge, or the export of machines, or tools, or coal, or materials of any kind, can long or effectually be interfered with; but position, climate, mineral wealth, energy of the population, and similar natural characteristics, are those only which, in the long run, will determine the localisation of trades of various kinds. Still, when we hear, as we do at present from all sides, bitter complaints as to foreigners supplying themselves with commodities which we formerly sent to them, it may be well to remember that these "giants" of competition we so much dislike are simply the natural outgrowth of the "dragons' teeth," which we ourselves have sown in time past, and which we continue day by day to sow in various directions.

It seems to me that it is part of the vocation to which we are all proud to belong, that we should ever strive to adapt ourselves to the varying necessities of the times as quickly and completely as possible, and do our best to make all others within our control do the same. Whatever success we have had in times past has been due to the study of nature's laws, and not to resistance of them. The cases of American watch-making and bridge-building, and Hungarian roller-milling (and there are many more), should show us we are not always in the van of progress. But we must not be too much afraid of the spectre of over-production. There seems strong reason after all for suspecting that we have been right in regarding over-production and mechanical progress as running in parallel grooves. It is perhaps conceivable that ladies may even prefer a single yard of hand-made lace to 8,000 yards made by a lace-making machine. But it is not conceivable that, after learning the utility of the steam-navvy, engineers should discard its use in excavating the Manchester Ship Canal, and employ a hundred times more men instead. We cannot impede the fall in value resulting from increased facilities of production; but we may gather consolation from the reflection that trade revivals have always been based on low and not on high values.

Low values and low costs however are not altogether due to improved machinery. They are quite as much due to improved humanity—to the raised moral tone and more reasonable personal habits, which are the natural result of long continued pressure.

Depression of trade must be largely influenced by the degree of wastefulness, national and individual, past and present, which prevails, and which we should notice far more if we were not so accustomed to it. This is of course a matter not for mechanical engineers only, but for every one. For waste on the part of any one really affects every one. We are suffering from the waste of our forefathers, as well as from our own; and posterity will perhaps suffer from still further burdens. The interest of our national debt, which represents some of the waste of past generations, amounts to about 17*s.* per head of the population. The average annual expenditure per head in railway travelling is a little less than this. If therefore our ancestors had not indulged in the luxury of wars beyond what they could pay for, every inhabitant of this realm might now be in the enjoyment of a free pass over all the lines in the country. It is obvious that such a boon, if now obtainable, would go far to bring about a revival of trade. I am not prepared to say the time has arrived when the services of our army and navy can be dispensed with; but if they could, we should thereby save what would pay three-fourths of the cost of the entire railway goods traffic of the country.

The depression of trade has no doubt been due in some measure to public wastefulness of other kinds. The whole business of legislation, and even that of administration, are carried on less economically than they might be, and than they actually are carried on in some other countries. In properly conducted private enterprises, every member of the organisation works in unison with every other member to gain the ends which are their common *raison d'être*. But in the greatest and most important business of all, namely the business of the state, nearly half those concerned are usually intent on opposing to the utmost, and even obstructing, what the rest do or try to do. So much of the time and energy thus

expended as is unproductive of good, must clearly be accounted as waste, and as a burden tending towards depression of trade. The cost of parliamentary elections, by whomsoever borne, and the stoppage of business resulting therefrom, must act as an incubus upon trade, especially when they come in rapid succession, as of late.

Sir Bernhard Samuelson, in a recent report read by him before the Associated Chambers of Commerce, states that, except in certain cases of raw material, continental railway rates are so much lower than ours as to place our traders at a serious disadvantage. This is not altogether attributable to the cupidity of directors. Our earlier and leading railways were regarded as evils by nearly as many as regarded them as benefits. Their Acts were usually obtained only under violent opposition, involving greatly enhanced cost. The amounts paid for land and for compensations were, owing to excessive litigation, unduly heavy. Consequently the first cost of our railways, as a whole, has been far in excess of those of other countries, where the peoples and their governments were all eager to promote them.* † When therefore railway companies plead, as they have lately been doing, that they pay only a moderate interest on their expended capital, and that therefore their rates should not be interfered with, it must be taken into account that, but for wasteful construction in the way mentioned, much lower traffic rates would suffice to pay the same interest. Here again present trade is burdened by follies of the past.

---

* According to statistics published by the "Archiv für Eisenbahnwesen," and quoted in "Iron" of 23 July 1886, page 80, the cost per mile of making the railways of different countries has been as follows:—Great Britain, £41,168; France, £24,928; Belgium (state railways), £24,797; Germany (state railways), £21,041; Austria, £20,885; Russia, £16,449; United States, £12,650.

† Since the above was written I have been informed by Mr. J. S. Jeans, Secretary of the British Iron Trade Association, that the cost per mile of British railways, given by the German publication, is below the truth. Mr. Jeans says that if Great Britain alone be taken, the cost per mile at the end of 1885 amounted to £47,027 per mile; but if Ireland be included, then £42,561 per mile would be the cost. This correction tends rather to increase than to diminish the force of my argument.

As far back as 1758, Dr. Franklin,* addressing his neighbours on the bad times, of which it appears men were then complaining just as we now are, said:—"The taxes are indeed very heavy, and if those laid on by the government were the only ones we had to pay, we might more easily discharge them. But we have many others, and much more grievous to some of us. We are taxed twice as much by our idleness, three times as much by our pride, and four times as much by our folly; and from these taxes commissioners cannot ease or deliver us."

The proverbial pertinacity and even pugnacity of the Teutonic character on the whole stand us Englishmen in good stead. But they also often lead us by indiscreet or excessive fighting to waste time and energy, and to accumulate debts which thereafter burden our industry for all time. The great losses which have occurred through the industrial strikes of the last twenty years will be remembered by every one. The troubles entailed by them were by no means over when peace was restored. Our technical paper "Iron" quotes an authority who has been computing the cost of the recent strikes in the United States. This writer estimates the aggregate loss which occurred there within three weeks at not less than £6,000,000, representing at 5 per cent. a perpetual tax on the American industries concerned of £300,000 per annum, and nothing to show for it! Although we in England cannot boast of having ever done anything quite so "big" in the way of strikes as our American cousins, still we are always doing a little, and whenever under-production prevails we do a great deal. How much of the present depression of trade is due to the accumulated burdens laid on by strikes, I cannot say. But I am certain that, if the money wasted on the admittedly futile and needless strikes alone could now be recovered, and be devoted to the good of British industry, we should hear no more of depression of trade for a long time to come.

Another great burden upon trade in England is the pauperism which has been fostered by our poor-law system and by its administration in the past. In the town to which I belong, and

* See Franklin's Life and Essays.

where trade has for long been suffering greatly, the effects are exceptionally glaring. Out of 89,000 to 90,000 inhabitants, 6,000 to 7,000 have, during the current year, often been at one time in receipt of pauper relief; and 800 to 900 are usually in the workhouse. That establishment is indeed by far the largest and best filled, though most unpopular, hotel in the place. The poor-rate laid on to pay for all this tends to keep down trade. The majority of those who are compelled to contribute are themselves struggling to make both ends meet, and many have found in it the proverbial "last straw." None of the continental nations have, I believe, a poor law on the same principle as ours; and they appear to be less troubled with pauperism than we are. Indeed the English poor law may fairly be described as a premium on thriftlessness, and a tax on thrift; and there is little doubt but that the depression of trade is traceable in no small degree to the discouragement which it engenders among the operative class against habits of self-reliance.* Another and distinct piece of folly and injustice in connection with this matter is that poor-rates are local, instead of being national as they should be if made at all. Surely the rich should bear at least their full proportion of the cost of maintaining the destitute; and should not be able, by congregating exclusively in fashionable neighbourhoods, to throw the whole onus of the pauperism in less favoured localities upon the overburdened and struggling workers and traders thereof.

This is perhaps scarcely the time or place to enlarge upon immoralities, such as drunkenness, gambling, &c., which are only too familiar to us all. Still no reference to the causes of depression

* Last winter the Middlesbrough guardians, in an honest endeavour to relieve some of the prevalent distress, opened several stone yards, the operatives there being paid very low wages according to their families and not according to the work done. The average number of men employed was 598, and 13,500 tons of slag were broken. It was found however that the broken slag cost 10*s.* 9½*d.* per ton, and the market value was 9*d.* per ton, so the yards were closed. The loss sustained by the rate-payers was £6511 15*s.* 2*d.*, or 10*s.* 0½*d.* per ton. This result should be well pondered by all those who advocate state employment of the otherwise unemployed.

of trade would be complete without mention of them. Our assize judges, in their opening charges, have over and over again declared them to be the principal causes of crime, insanity, and destitution; and therefore of the expenses which the trade of the country has to bear, for prisons, asylums, police, and so forth. I notice also that in the reports of the Royal Commission, some of the witnesses have not hesitated to speak in no faltering manner of these well-known perennial causes of trade depression. It is to be hoped that the civilising effect of more extended and more thorough national education, as well as the lessons taught by prolonged adversity, will, as time goes on, raise the moral tone of our industrial classes, so as to enable them to free themselves and the trade of the country from all those voluntary and more onerous taxes to which Dr. Franklin so quaintly alluded.

When discoursing on depression of trade, low prices, and over-production, we must not forget that, whatever outcry there may be against these supposed evils, it comes, not from the whole community, but only from the producing or trading portion thereof. There is another and opposite side to the question. As *consumers*, all benefit from the cheapness which proceeds from over-production. To those who have absolutely no employment and no money, it is certainly no consolation that everything is cheap; and there are unfortunately sufficient of these in our midst at present to warrant a very great outcry. But compared with the whole nation, the unemployed and destitute are only a small percentage. And of the rest, that is of the majority, very many are as well off as ever, and some are reaping, and will reap hereafter, very substantial advantage. Intrinsically it cannot be a bad thing that commodities useful to mankind should be abundant and cheap; and no *buyer* ever yet complained of their being so. The outcry is altogether from those interested in the production or distribution of something; and, whether consciously or not, has reference to that something alone. Every one would naturally like what he sells and others buy to be dear; and what he buys and others sell to be cheap. Put in this undisguised form, the proposition is obviously untenable and absurd;

but numbers would and do entertain it, when disguised in the plausible language we so frequently hear used by partizans.

The fall in the market-price of the prime necessaries of life, during the last two or three years, has been from 20 to 30 per cent. The fall in wages has on the average certainly not been so great. It is therefore obvious that all belonging to the wage-receiving class who have been so far fully employed have not suffered at all. The numerous class of persons who have fixed pecuniary incomes must have substantially benefited by the increased purchasing power of money. And as to the wealthier classes, it is certain that all who have the command of capital available in money, such as deposits in banks, loans on ample security, and so forth—as distinct from capital in the form of property of fluctuating value, such as land, works, ships, and so forth—must have been enormously benefited by the general fall in values.

It would seem certain that the long hoped-for revival of trade must, when it comes, proceed from the initiative of this monied class. The more or less impoverished industrial or trading class is powerless. A re-marriage is needed between the lately divorced interests, money and industry; and that reunion must be the outcome of a renewal of confidence. The loss of confidence by the monied class has no doubt been largely the fault of the industrial or trading class, and is the natural punishment for by-gone follies and waste of various kinds. But punishments should not last for ever; and if they endure too long, they are apt to produce a reaction which tends to lessen their proper effect. The time must be near when monied men will see that values are not likely to go lower, and are even tending upwards, and that whatever is then purchased is certain to prove a lucrative investment. When that critical moment arrives, they will no doubt regain confidence once more, and open their purses, and set to work the lagging wheels of industry, to the great relief of the unemployed, and indeed of the entire industrial community.

In conclusion, I desire to thank you all for having listened so patiently to the remarks I have ventured to make. I am well aware that I have dealt with the subject only in a most

fragmentary and imperfect manner. I lay no claim to completeness; my intention has simply been to ventilate, from the point of view of a mechanical engineer, so far as the limited time at my disposal would permit, certain current notions, often repeated, and apparently accepted without very much consideration. I trust I shall not have appeared too dogmatic. Upon a question at once so wide and so complicated, one may well be content to do no more than offer suggestions. For a solution perchance of some of the enigmas involved, I invite you to look expectantly and hopefully to those "right trusty, and right well-beloved cousins and councillors, and those trusty and well-beloved esquires," whom Her Majesty, "reposing great trust and confidence in their knowledge and ability," has "authorised and appointed," and "willed and ordained" to report to Her, whether the prevailing depression of trade and industry "can be alleviated by legislative or other measures."

Mr. GEORGE B. RENNIE proposed a hearty vote of thanks to the President for his very interesting Address. There were so many points in it which more or less affected mechanical engineers, and there was so much matter in it for reflection, that it would be necessary for everybody to study it before they could deal with it in detail. They must all recognise with the President that there was a depression in trade; but it was a very difficult thing to say what the remedy was. The President had pointed out certain causes of the depression, and no doubt the main cause was over-production, both in this country and in other countries: more things were really made than were required at present. Presumably after a time this would mend itself; things wore out, or got destroyed, or from a variety of other causes had to be renewed. In the meantime it was to be hoped that mechanical engineers would profit by the President's Address,

and would endeavour to produce their several manufactures in a cheaper and better way than could be done by other nations, so that this country might receive the benefit. As Chairman of the Local Committee he wished to say a word with respect to the allusion made to the summer meeting in the President's introductory remarks. The Committee had done what they could to render the meeting as interesting as possible for all the members, and for the Belgian Engineers who had been good enough to attend. The members in London felt that they had been treated so well in provincial towns, and three years ago by their friends at Liége, that they wished in return to do all they could to render the present meeting as agreeable as possible. Fortunately they could not have had a better person to make all the arrangements acceptable to the members and the visitors than the Honorary Secretary, Mr. Henry Chapman, who to a very great extent had taken the labour off the hands of the rest of the Committee.

Mr. E. H. Carbutt was proud to belong to an Institution whose President could deliver such an able Address as they had just listened to. Having himself taken some trouble in reading the evidence given before the Royal Commission on the Depression of Trade, he could all the more heartily say how greatly he wished their President had either been a member of that Commission or had given evidence before it; because he was quite sure the Meeting would agree with him—in fact they had shown they did so by the applause with which they had greeted the Address—that no one had treated the subject in a broader or more comprehensive manner than the President had now done. It would ill become him to discuss the details of the Address; but he thought as mechanical engineers they ought to agree with their President when he said they must not be too much afraid of the spectre of over-production. They could not expect foreign nations to give up producing and competing with them; and what they had to do was to make the best use they could of the abilities with which they were endowed. Let them educate their young men in technical colleges, and lead them to devise improved machinery for the cheaper production of all manufactured

(Mr. E. H. Carbutt.)
articles; because, the cheaper they could produce anything, the more would they add to the happiness not only of this country but of the world in general. The cheaper men could live, the more likely were they to become peaceable and happy citizens in this world. He felt sure that not only their friends from Belgium, but everyone else present, would be delighted with the President's Address. Some points of course might be criticised; but there was no occasion to do more now than point out that the President had here shown them how everything which was consumed had become cheaper than it was years ago. The only things that had gone up were rent and taxes; and it was for them to look after the legislature, so that these two things should be properly dealt with; because they might depend upon it that, if taxation went on increasing at the same rate as in the past, the country would speak out. He did not quite agree with the invitation at the end of the Address to look expectantly and hopefully to Her Majesty's "well-beloved cousins." It was for mechanical engineers, as for other members of the community, to speak out, and to say that they would either have less taxation or would get more for the money that was raised in taxes. He had great pleasure in heartily seconding the motion that their best thanks be given to the President for the Address he had delivered, and for the great pains he had taken in preparing it for the Institution.

The vote of thanks was put to the Meeting and cordially agreed to.

The President said he was extremely obliged to Mr. Rennie, to Mr. Carbutt, and to the Meeting, for the resolution which had just been passed. He assured them that after he had prepared the Address he had had many misgivings lest it should not be up to the standard required. He was therefore all the more pleased with the kind reception which had been accorded to it.

EXPERIMENTS ON THE STEAM-JACKETING AND COMPOUNDING OF LOCOMOTIVES IN RUSSIA.

By Mr. ALEXANDER BORODIN, Engineer-in-Chief, Russian South-Western Railways, Kieff.

In consequence of the satisfactory results obtained by M. A. Mallet in applying the Compound system to the Locomotives of the Bayonne and Biarritz Railway, the Russian South-Western Railways in 1880 altered a locomotive to the compound system in accordance with M. Mallet's plans. At the same time another locomotive was provided with steam-jacketed cylinders.

It accordingly became desirable to make comparative tests with these engines. The whole of the experiments and investigations hitherto made, on the work of locomotive engines as well as on their consumption of fuel and water, appeared to the author to be deficient in completeness and accuracy, and based on data not sufficiently scientific. Struck by Mr. G. A. Hirn's remarkable practical theory of the steam engine, and by his beautiful method of investigation as developed by Mr. Hallauer and other Alsatian experimenters, the author was led to adopt the same method for his own researches on locomotives. It was thus the idea was originated of erecting a locomotive testing shop, in which a great number of the comparative tests were carried out.

But as Hirn's method had so far been applied to condensing engines only, some modifications had to be introduced in order to adapt it to locomotives working without condensation. For this purpose, and in order to clear up some points of detail, the author went to Colmar in 1880 to consult Mr. Hirn; and he wishes to acknowledge how materially his investigations have been aided by the consideration, forethought, and advice of this illustrious engineer.

Another part of the trials was carried out by means of experimental trains; and in these the method adopted for the calculation of the work done, as well as of the consumption of steam and fuel, is due entirely to Mr. L. Loevy, locomotive engineer of the Russian South-Western Railways, by whom the whole of the trials were carried out.

PART I.—TESTS MADE IN THE LOCOMOTIVE TESTING SHOP.

A great number of tests, having for their object the investigation of the work done by the steam in locomotives, were carried out in the testing shop, which had already been proposed by the author in 1881.*

The whole of the arrangements in this testing shop were temporary; and as the author was not in possession of a friction brake capable of taking up the whole power given out by a locomotive, it was necessary to work the engine so as to develop not more than about 90 horse-power, which was used for driving the machine tools in the Kieff workshops. On this account the tests had to be carried out with high grades of expansion and comparatively low pressures. The arrangements were advantageous for carrying out the experiments with rapidity and ease, as well as for obtaining all the verifications desired, including calorimetric tests as a check on the results arrived at.

Description of the Testing Shop.

The arrangement of the temporary testing shed is shown in Plates 64 to 66. The locomotive, detached from its tender, was placed outside the Kieff repairing shop, at right angles to the side A of the building, Figs. 1 and 4; and the engine, as well as all the apparatus used, was protected from the weather by a shed. The driving wheels were raised slightly above the rails, Fig. 1, the coupled wheels were uncoupled, and the driving wheels were

* Organ für die Fortschritte des Eisenbahnwesens, 1881, Hefte 4 & 5.

transformed into driving pulleys. By means of belting they worked pulleys on an intermediate shaft SS, which communicated the motion to the main driving shaft in the repairing shop. The diameters of the pulleys were so proportioned that the locomotive could make 92 to 102 revolutions per minute, corresponding with speeds of $17\frac{1}{2}$ to $19\frac{1}{4}$ miles per hour. As the exhaust steam was condensed in a tank, and therefore could not be utilised for augmenting the draught, it was necessary to lengthen the chimney of the locomotive in order to obtain sufficient draught. During the whole time of each test, which lasted from $1\frac{1}{2}$ to $3\frac{1}{2}$ hours, the locomotive worked at the same degree of expansion, with the regulator open to the same extent, and as far as possible at the same speed and with the same boiler pressure. The power given off by the engine was kept constant, and was equal to the minimum power necessary to drive the tools in the workshop; any additional power required was provided by the shop engine. The slight irregularities which occurred during the tests, through increase of pressure or of speed, were allowed for as will be described.

The locomotive was provided with the following appliances for making observations:—

(1) A double pressure-gauge, which had been verified with an open mercury column;

(2) A revolution-counter C, Fig. 1, Plate 64, recording the number of revolutions of the engine;

(3) A pressure-gauge G for showing the pressure in the steam-jackets;

(4) Indicators I I on each cylinder, whereby diagrams could be taken from each end.

The water-gauge on the boiler was provided with internal baffle-plates, as shown in Figs. 9 and 10, Plate 67, so as to prevent oscillations in the glass tube.

In order to collect the exhaust steam from the cylinders, so that its weight might be determined as well as the number of thermal units it contained, as a check upon the consumption of water and the degree of moisture in the steam on leaving the boiler, the following arrangement was adopted. On a raised

stage was placed a tank T, fitted with diaphragms, Figs. 3 and 5, Plates 65 and 67, and provided with an adjustable overflow M, which served to regulate the level of the water brought into the tank T by the supply pipes BB, and to discharge the surplus water into the side pocket K, and thence into the pipe D. The lower part of the tank was provided with an orifice F in a thin plate, Fig. 5, shown also to a larger scale in Fig. 6. The cold water continuously running into the tank T flowed away freely through the orifice F under an almost constant head above the centre of the orifice, which was easily maintained by means of the adjustable overflow M, supplemented by the cocks regulating the supply through the pipes BB. Besides this however, the head above the orifice was further measured by means of a glass water-gauge (Figs. 2 and 3) provided with a scale. The water flowing steadily out of the tank T into a trough R passed thence through an opening in the bottom of the trough, into the bent-up pipe X, and thence into a larger pipe Y, similarly bent, across which, as shown in Fig. 5, was a grating covered with a layer of coke; after passing through the coke and the grating, the water fell in a shower of rain through a pipe of large diameter, into a large tub V, meeting on its way the exhaust steam from the cylinders, which was brought by the pipe E (Figs. 2 and 4) into the jacket J, and thence entered through numerous openings into the large rain-pipe. The exhaust steam, being thus brought into contact with the shower of rain, was partially condensed, and the mixture of water and steam fell into the tub V, where it mixed with the water in the tub, the level of which was constantly maintained high enough to keep the bottom of the rain-pipe always sealed, so as to prevent escape of uncondensed steam.

The lower part of the tub V was provided with an orifice H in a thin plate, Figs. 2 and 5, Plates 64 and 67, exactly similar to the orifice F in the tank T, through which flowed away the warm water resulting from the mixture of cold water and condensed steam. The tub V was also provided with internal diaphragms, as shown in Fig. 5, for steadying the flow of the water, so that the water-level might easily be read off by means of a glass water-gauge, Fig. 2.

The tank T and tub V were provided with thermometers, placed near the orifices F and H. Although these two orifices were made with the same drill of $1\frac{1}{2}$ inch diameter, the quantity of water flowing through them was not exactly equal, the difference amounting to about $\frac{1}{2}$ per cent.

The purpose of the arrangement above described is self-evident. The quantity of cold water flowing out of the upper tank T can be accurately determined, as the head is known, as well as the conditions of discharge through the orifice F; the discharge of water from the lower tub V can be similarly determined. Consequently the difference between the two discharges from the upper and the lower vessel represents (after making some necessary corrections) the quantity of steam condensed, which can be used as a check on the consumption of feed-water that has been measured directly. The difference of temperature between the upper and the lower vessel renders it possible to calculate the quantity of heat in the exhaust steam; whence can be determined the quantity of water carried over by the steam from the boiler.

In order to measure directly the quantity of feed-water used, a vessel P was provided, Fig. 3, Plate 65, which had been previously gauged, and which was fitted with a glass water-gauge; from this vessel the feed was taken through the pipe N by means of an injector, and the overflow from the injector was collected and measured in a wrought-iron tank W, Fig. 3. The vessel P was refilled when necessary from the overflow of the tank T by means of the pipe D, Fig. 2, an intermediate receiver L, and a cock.

Mode of conducting the Tests.

The duration of each test varied from $1\frac{1}{2}$ to $3\frac{1}{2}$ hours. Throughout the whole duration of the test the pressure-gauge readings were noted every minute; the number of revolutions was counted every five minutes at the same time that the indicator diagrams were taken; this was independent of the readings noted from the counter. The water-levels in the upper and lower tanks T and V, as well as the thermometer readings in the latter, were noted every minute, the thermometer readings in the upper tank T being

taken every ten minutes only, because the temperature of the cold water was nearly constant during the whole of each experiment. The water-level in the boiler, as well as the reading of the counter, was taken at the commencement and at the end of each experiment. Finally, the wood used as fuel was weighed, although this information had no direct bearing on these tests, their only object being an analysis of the work done by the steam engine.

The observations thus made, after having undergone all the necessary corrections, furnished the following data for each test:—

(1) The total consumption of moist steam, ascertained by direct gauging of the feed-water.

(2) The consumption of moist steam per revolution of the engine, obtained by dividing the total consumption by the total number of revolutions.

(3) The mean number of revolutions per minute for the whole duration of the experiment.

(4) The mean boiler-pressure, and the mean temperatures of the cold condensing water in the tank T, and of the warm water flowing away from the tub V.

(5) The mean head of water above the centre of the outlet orifice in the tank T and in the tub V.

(6) The mean forward pressures and back pressures in the cylinders during the whole experiment, and separately for the front and back end of each cylinder.

(7) The mean indicated power developed during the whole of the experiment.

(8) The consumption of moist steam per indicated horse-power per hour. When the steam-jackets were at work, the steam consumption was measured both inclusively and exclusively of the water condensed in the jackets.

The consumption of steam per hour was also calculated per absolute horse-power on the supposition of the piston working against a perfect vacuum.

(9) The consumption of steam for heating the jackets; for this purpose the jackets were fitted with the self-acting steam-trap shown in Fig. 7, Plate 67, for discharging the condensed water, which was then weighed.

Verification of the quantity of Water carried over by the steam.

The following symbols are adopted for this calculation :—

Q the weight in kilograms of the water discharged from the upper into the lower tank during the whole experiment.

M the total consumption in kilograms of moist steam by the cylinders during the same space of time.

m the weight in kilograms of the water condensed in the jackets.

t_0 the mean temperature centigrade during the whole experiment of the cold water issuing from the tank T.

t_1 the mean temperature centigrade of the warm water in the tub V.

t_2 the mean temperature centigrade of the steam in the boiler.

q_0 q_1 q_2 the number of calories contained in one kilogram of water at the temperatures t_0 t_1 t_2.

q_3 q_4 do. at the temperatures of the water in the lower tub V at the beginning and at the end of the experiment.

x the mean quantity of dry steam contained in one kilogram of moist steam furnished by the boiler.

T the total indicated power developed during the experiment, in kilogrammetres.

R_e the number of calories lost during the experiment by external cooling.

A_1 A_2 the weight in kilograms of the water contained in the tub V at the beginning and at the end of the experiment.

From the principles of the mechanical theory of heat, and taking 424 kilogrammetres as the mechanical equivalent of one (French) thermal unit, the following equation is arrived at when the jackets are not at work and when the external cooling R_e is neglected :—

$$\left\{Q+M+(A_1-A_2)\right\}q_1+A_2\,q_4+\frac{T}{424}=$$

$$=M\,x\,(606\cdot5+0\cdot305\,t_2)+M\,(1-x)\,q_2+Q\,q_0+A_1\,q_3;$$

whence

$$x=\frac{Q\,(q_1-q_0)+M\,(q_1-q_2)+\frac{T}{424}+A_1\,(q_1-q_3)+A_2\,(q_4-q_1)}{M\,(606\cdot5+0\cdot305\,t_2-q_2)} \quad \ldots\ (1)$$

and for the whole test the mean percentage of water carried over by the steam from the boiler will be $100\,(1-x)$. As the whole of the

values in the second half of this equation are known from the experiments, the equation serves to determine the percentage of water carried over in each test.

When the jackets are at work, the steam condensed gives up one part of its heat m $(606{\cdot}5 + 0{\cdot}305\ t_2 - q_2)$ to the steam working in the cylinders, and the other part R_e to the outside atmosphere, so that it is necessary to add to the numerator in the second half of equation (1)

$$\left\{m\ (606{\cdot}5 + 0{\cdot}305\ t_2 - q_2) - R_e\right\}$$

prefixing the negative sign $(-)$.

In all these experiments that were made with an ordinary locomotive, the value R_e was taken—in accordance with the results obtained by Hirn and Peclet as to the external cooling of cylinders and steam pipes—at 0·5 calorie $(= 1{\cdot}98$ British thermal unit) for each cylinder and each revolution: which was so small that it was not deemed necessary to make direct experiments on the external cooling of the jackets employed.

As almost all the tests were carried out under conditions more or less similar—that is to say, with only slight differences in pressure, speed, and consumption of steam—the quantity of water carried over by the steam should be approximately the same in all the experiments. Therefore the comparison of the values obtained for x or 100 $(1-x)$ gave an idea of the degree of accuracy with which the experiments had been made and the calculations worked out. Furthermore, whenever the proportion of water carried over in any one experiment differed much from the mean values, this led to the suspicion and often to the detection of errors, whether of observation or of calculation.

Verification of the Consumption of Moist Steam.

The methods of gauging the water flowing from the tank above and from the tub below, as well as of measuring the consumption of moist steam by the cylinders, have been already described. As the whole of this steam (with the exception of accidental leakages) passed into the lower tub along with the cold water from the upper

tank, the weight of the water flowing out from the lower tub should, after allowing for the difference of water-level at the beginning and end of the test, be equal to the weight of the water flowing from the upper tank together with the weight of the steam that has passed through the cylinders. The difference between these two values will indicate the degree of accuracy with which the quantities of water flowing from these two vessels, and also the quantity of the feed-water, have been measured; or, what is the same thing, the difference between the quantities of water flowing out of the upper and lower vessels will give the consumption of steam in the cylinders, which was directly gauged as feed-water. This means of verification rendered it possible to correct some errors that may always occur, and to detect inaccuracies in some of the tests.

Results obtained from Tests made in 1882 *with an Ordinary locomotive* A 22 *steam-jacketed.*

This series of tests was made with a passenger engine, built by Cail, having four wheels coupled, and outside cylinders provided with steam-jackets, into which steam was supplied direct from the boiler through special pipes; the condensed water escaped from the jackets through the automatic steam-trap shown in Fig. 7, Plate 67. The steam could at pleasure be shut off from the jackets, so as to throw them out of action. Throughout the whole of these tests one cylinder only was working, the other being disconnected from the driving axle.

The following were the leading dimensions of the engine:—

Diameter of driving wheels	5 ft. 6·93 ins.
Diameter of cylinders	16·54 inches.
„ piston-rods	2·60 inches.
Area of piston, front face	214·7 sq. ins.
„ back face, deducting area of piston-rod	209·2 sq. ins.
Length of stroke	23·62 inches.

The clearances were determined by filling them with water when the piston was at the ends of its stroke; the front clearance was 7·3 per cent. and the back 8 per cent. of the volume described by the

stroke of the piston. The slide-valves had 0·98 inch lap outside, and 0·04 inch inside; and were worked by Stephenson link-motion. With the reversing lever in the first and second notches the setting of the slide-valve was also varied in different tests, so as to give altogether seven different distributions of steam, of which some of the details are furnished in Table 1 on the opposite page.

As already explained, all the trials had to be made while the engine was developing no more than only 90 horse-power. Consequently, even though working with only one cylinder, the tests had to be made with the reversing lever in the second or first notch of the quadrant, so as to cut off the steam as early as 30 or even 20 per cent. of the stroke, and with low boiler-pressures of not more than from 45 to 78 lbs. per square inch above the atmosphere.

The results obtained from the thirty-five experiments that were made are given in Table 2, pages 308 to 311. The figures relating to the tests in which the steam-jacket was working are there indicated in distinctive type; and the following explanations are necessary.

Column 20 shows the degree of accuracy with which the quantities of water flowing from the upper and lower vessels were determined. In the majority of the experiments the differences did not exceed 0·2 and 0·3 per cent.; in five they reached 0·4 and 0·5 per cent.; and in five they amounted to 0·6 and 0·7 per cent. Part of these differences must be attributed to the gauging of the consumption of feed-water, in consequence of the difficulty of accurately determining the water-level in the boiler.

Column 21 shows the limits of the possible errors in the gauging of the water consumed. In twenty-one of the experiments these limits did not exceed 4 per cent.; in four they reached 5 and 7 per cent.; and in seven they sometimes amounted to 10 and 11 per cent. These values have been arrived at on the supposition that the quantities of water flowing out of the upper and lower vessels were accurately measured; whatever errors may possibly have occurred in these measurements, the consequent errors in the estimation of the quantity of feed-water are evidently less.

TABLE 1.—*Details of seven different Steam Distributions.*

Steam Distribution. No.	Front or Back end of cylinder.	Lead. Linear. Inch.	Lead. Per cent. of cyl. area.	Maximum Opening of Steam Ports. Linear. Inch.	Maximum Opening of Steam Ports. Per cent. of cyl. area.	Cut-off. Per cent.	Travel of Valve. Ins.	Tests. Nos.
		Reversing lever in *second* notch.						
I.	front	0·31	1·78	0·38	2·17	30·0	2·40	1 to 4
	back	0·12	0·67	0·19	1·03	28·5		
II.	front	0·18	1·04	0·25	1·45	25·3	2·40	5 to 12
	back	0·13	0·73	0·25	1·42	34·4		
III.	front	0·15	0·84	0·24	1·34	23·7	2·40	13 and 14
	back	0·15	0·84	0·31	1·78	36·7		
IV.	front	0·22	1·23	0·32	1·84	26·9	2·42	15 and 16
	back	0·12	0·67	0·30	1·62	32·7		
V.	front	0·29	1·65	0·38	2·17	29·4	2·42	17 to 28
	back	0·04	0·22	0·24	1·34	30·0		
		Reversing lever in *first* notch.						
VI.	front	0·31	1·78	0·33	1·90	22·0	2·36	29 to 31
	back	0·03	0·17	0·08	0·45	17·2		
VII.	front	0·27	1·54	0·30	1·67	19·5	2·36	32 to 35
	back	0·09	0·53	0·14	0·78	19·7		

TABLE 2 (*continued to page* 311)

Tests made in 1882 *with an Ordinary Locomotive* A 22 *Steam-Jacketed.*

1	2	3	4	5	6	7
Number of Test.	Position of Reversing Lever.	Steam Distribution. (See Table I.)	Steam-Jacket Working or Not working.	Mean Boiler-Pressure above atmosphere. Lbs. per square inch.	Mean Revolutions per minute.	Duration of Test.
No.	Notch.	No.		Lbs.	Revs.	Minutes.
1	2	I	not working	68·6	101·45	222
3	2	I	not working	62·3	96·86	100
2	2	I	working	61·7	101·02	210
4	2	I	working	64·5	102·34	210
5	2	II	not working	60·6	102·12	85
11	2	II	not working	56·0	103·57	140
12	2	II	not working	55·3	97·42	208
6	2	II	working	58·1	101·26	192
7	2	II	working	60·7	100·72	102
8	2	II	working	61·2	100·58	212
9	2	II	working	58·4	99·41	110
10	2	II	working	56·2	99·83	216
13	2	III	not working	55·4	95·91	119
14	2	III	not working	54·4	92·10	182
15	2	IV	working	55·1	99·95	149
16	2	IV	working	55·6	102·69	211
17	2	V	not working	52·3	92·94	212
18	2	V	not working	51·6	98·14	116
19	2	V	not working	50·6	95·64	210
20	2	V	not working	46·9	96·28	143
21	2	V	not working	45·0	98·94	123
27	2	V	not working	51·3	91·98	122
28	2	V	not working	48·5	91·23	191
22	2	V	working	47·6	94·06	217
23	2	V	working	47·8	96·07	132
24	2	V	working	45·7	94·58	204
25	2	V	working	55·4	95·24	113
26	2	V	working	53·2	91·92	188
29	1	VI	not working	76·4	94·17	99
30	1	VI	not working	76·7	91·89	179
31	1	VI	working	77·8	93·12	130
32	1	VII	working	78·1	92·92	112
33	1	VII	working	77·8	94·42	203
34	1	VII	not working	75·6	91·88	112
35	1	VII	not working	75·0	91·98	200

(*continued on next page*) TABLE 2.

Tests made in 1882 *with an Ordinary Locomotive* A 22 *Steam-Jacketed.*

1	8	9	10	11	12	13	14
Number of Test.	Consumption of Moist Steam per revolution, by direct measurement of feed-water.			Mean Cylinder Pressures above atmosphere, measured from indicator diagrams. Lbs. per square inch.			
				Forward Pressure.		Back Pressure.	
No.	In Cylinder. Lb.	In Jacket. Lb.	Total. Lb.	Front end. Lbs.	Back end. Lbs.	Front end. Lbs.	Back end. Lbs.
1	0·32688	...	0·32688	33·63	26·05	6·67	8·86
3	0·29839	...	0·29839	32·58	25·34	6·03	8·57
2	0·29098	0·00675	0·29773	33·53	24·70	6·60	9·28
4	0·27862	0·00666	0·28527	35·52	27·50	6·41	8·54
5	0·29996	...	0·29996	26·18	33·90	8·64	7·28
11	0·27170	...	0·27170	25·70	31·90	8·17	8·31
12	0·27318	...	0·27318	25·15	31·52	8·31	7·86
6	0·25375	0·00672	0·26047	26·22	33·12	8·51	7·60
7	0·29504	0·00708	0·30212	27·39	34·05	8·26	7·41
8	0·27077	0·00675	0·27752	27·34	34·99	8·61	7·86
9	0·26975	0·00686	0·27662	25·97	33·38	8·32	7·89
10	0·24619	0·00756	0·25375	25·23	32·19	8·21	7·84
13	0·26541	...	0·26541	21·18	30·41	8·50	7·09
14	0·27081	...	0·27081	22·62	30·52	7·81	7·07
15	0·22044	0·00622	0·22666	22·55	30·05	8·63	7·36
16	0·21634	0·00608	0·22242	23·40	30·86	8·97	7·64
17	0·25443	...	0·25443	24·83	25·75	6·89	7·31
18	0·25253	...	0·25253	23·73	24·78	6·14	7·00
19	0·26179	...	0·26179	23·12	24·11	5·87	6·34
20	0·22418	...	0·22418	22·40	23·09	5·76	6·88
21	0·20560	...	0·20560	20·36	20·59	6·22	7·28
27	0·23969	...	0·23969	22·74	23·93	6·64	7·36
28	0·24862	...	0·24862	21·02	21·99	5·69	7·03
22	0·18201	0·00657	0·18858	22·61	22·92	6·97	7·69
23	0·18812	0·00712	0·19524	22·29	22·67	7·00	7·67
24	0·17835	0·00675	0·18510	21·36	21·68	6·63	7·54
25	0·22842	0·00778	0·23620	26·17	28·37	6·51	7·23
26	0·22097	0·00789	0·22886	24·90	26·28	6·64	7·45
29	0·26414	...	0·26414	29·61	28·24	9·19	9·06
30	0·26299	...	0·26299	29·05	27·84	9·23	9·10
31	0·24621	0·00820	0·25441	31·02	30·63	10·00	9·95
32	0·23789	0·00869	0·24658	30·09	35·47	10·17	10·03
33	0·23016	0·00747	0·23763	29·61	34·85	11·35	9·97
34	0·26973	...	0·26973	26·90	32·22	11·33	10·25
35	0·27372	...	0·27372	28·12	32·93	11·07	9·72

TABLE 2 (*continued from preceding page*)

Tests made in 1882 *with an Ordinary Locomotive* A 22 *Steam-Jacketed.*

1	15	16	17	18	19	20	21
Number of Test.	Mean Indicated Horse-power.	Consumption of Moist Steam per horse-power per hour.		Water Evaporated per pound of wood.	Wood used as fuel.	Percentage of Difference between Water discharge from condensing tank V, and sum of discharge from upper tank T plus steam consumption.	Percentage of Difference between Steam consumption measured direct, and calculated difference of water discharge from upper tank T and lower tank V.
		In Cylinder alone.	In Cylinder and Jacket together.				
No.	I.H.P.	Lbs.	Lbs.	Lbs.		Per cent.	Per cent.
1	57·5	34·55	34·55	3·54	mixed	...	...
3	54·0	32·14	32·14	...	,,	+ 0·1	− 1
2	55·0	32·03	32·78	3·59	,,	...	...
4	63·3	27·05	27·69	4·08	fir	...	...
5	57·7	31·86	31·86	3·46	fir	− 0·6	− 8
11	54·5	30·97	30·97	3·61	oak	+ 0·1	+ 2
12	50·5	31·61	31·61	3·71	,,	+ 0·05	+ 1
6	56·5	27·51	28·24	3·46	fir	0	0
7	59·0	30·23	30·51	4·34	,,	− 0·4	− 5
8	59·0	27·69	28·40	3·71	,,	+ 0·1	+ 1
9	49·9	29·32	30·07	3·28	,,	− 0·7	− 10
10	52·8	27·91	28·77	3·57	,,	+ 0·2	+ 4
13	44·1	34·61	34·61	4·08	oak	− 0·1	− 2
14	45·1	33·20	33·20	3·43	,,	− 0·2	+ 3
15	46·8	28·26	29·06	4·04	oak	+ 0·1	+ 2
16	49·4	26·96	27·71	3·90	,,	+ 0·1	+ 2
17	43·4	32·72	32·72	3·77	oak	+ 0·3	+ 4
18	44·5	33·40	33·40	3·96	alder	− 0·4	− 6
19	43·0	34·97	34·97	4·33	,,	− 0·6	− 8
20	40·6	31·92	31·92	2·92	,,	− 0·5	− 9
21	34·8	35·03	35·03	3·67	,,	+ 0·2	+ 4
27	38·4	34·33	34·33	4·92	mixed	+ 0·3	+ 5
28	35·5	38·38	38·38	4·09	,,	+ 0·6	+ 9
22	37·2	27·58	28·57	3·62	alder	+ 0·6	+ 11
23	37·3	29·06	30·16	4·18	,,	+ 0·1	+ 1
24	35·0	28·90	29·98	3·69	mixed	− 0·1	− 3
25	49·8	26·21	27·09	5·60	,,	+ 0·1	+ 2
26	43·7	27·89	28·88	4·15	,,	+ 0·1	+ 2
29	47·8	31·20	31·20	4·33	mixed	0	0
30	45·4	31·90	31·90	4·89	,,	− 0·1	− 1
31	49·8	27·62	28·53	5·17	,,	0	0
32	54·8	24·18	25·07	4·46	mixed	+ 0·5	+ 8
33	52·3	25·00	25·82	4·87	,,	+ 0·4	+ 7
34	44·1	33·69	33·69	4·40	,,	− 0·2	− 2
35	47·4	31·86	31·86	4·89	,,	+ 0·1	+ 1

(*concluded from page* 308) TABLE 2.

Tests made in 1882 *with an Ordinary Locomotive* A 22 *Steam-Jacketed.*

1	22	23
Number of Test.	Percentage of Water carried over by Steam. S denotes Superheating, as indicated by the minus sign −	For arrangement of upper tank T and lower tank V see Plates 64 to 67.
No.	Per cent.	* These ten corrections for col. 22 are arrived at by taking the mean of the consumptions directly measured and calculated.*
1	+ 4·5	Test 1, consumption not verified.
3	+ 0·6	
2	...	Test 2 unreliable, through bad leakage at cylinder covers.
4	+ 1·6	Test 4, see note A below.
5	+ 4·1	Test 5, col. 22 corrected = − 0·33 per cent.*
11	+ 3·5	
12	+ 5·6	
6	0·0	
7	+ 7·5	Test 7, col. 22 corrected = + 4·7 per cent.*
8	+ 1·9	
9	+ 6·0	Test 9, col. 22 corrected = + 0·2 per cent.*
10	+ 1·4	
13	+ 0·8	A { Test 4, consumption of feed-water could not be verified, owing to great variation of level in upper tank T through shortness of cold water.
14	+ 0·8	
15	− 1·3 S	Test 15, col. 22 corrected = − 0·4 per cent.*
16	+ 2·2	
17	+ 0·9	B { Test 20 unreliable, seeing that the steam was superheated 8 per cent., and that the evaporative duty of the wood and the consumption of steam per horse-power are both alike too low.
18	− 1·3 S	
19	+ 2·6	
20	− 8·0 S	Test 20, see note B above.
21	− 3·5 S	Test 21, col. 22 corrected = − 1·7 per cent.*
27	− 1·0 S	Test 27, ,, ,, = + 1·7 per cent.*
28	+ 0·1	Test 28, ,, ,, = + 5·4 per cent.*
22	− 7·5 S	Test 22, ,, ,, = − 0·7 per cent.*
23	− 2·6 S	
24	− 3·3 S	
25	+ 1·6	
26	...	Test 26, col. 22 blank, through irregular supply of water into upper tank T.
29	+ 6·4	
30	+ 3·2	
31	+ 3·9	
32	− 3·2 S	Test 32, col. 22 corrected = + 2·0 per cent.*
33	− 0·4 S	Test 33, ,, ,, = + 3·9 per cent.*
34	+ 0·9	
35	+ 1·0	

Column 22 shows the percentage of water carried over by the steam leaving the boiler and measured as previously described. At the same time this column gives an idea of the degree of accuracy with which all the observations and calculations were carried out. In the majority of the experiments, as here seen, the percentage of water carried over is small enough, not exceeding 4 per cent.; some experiments indicate a slight degree of superheating, not exceeding $3\frac{1}{2}$ per cent. Only eight tests have given a higher degree of moisture or of superheating, amounting in two experiments to $7\frac{1}{2}$ per cent. It must also be observed that in these last eight experiments columns 20 and 21 show less accuracy in the estimation of the consumption of feed-water, and of the quantities of water flowing out of the upper and lower vessels; whence it may be assumed that some error took place in the gauging of the water consumed. Taking the mean consumption between that directly gauged and that calculated from the difference of the water discharges from the upper and lower vessels, degrees of moisture are obtained in column 23 equal to those shown by the other experiments. Experiment No. 20 forms the only exception, and therefore is not to be relied on; the small consumption of steam per horse-power, the low evaporative duty of the wood used, and the high degree of superheating, all throw doubt upon the accuracy of the results obtained in this test.

Considering the large number of factors in equation (1) page 303, and the large number of observations and of minute and complicated calculations necessary for determining the degree of moisture in the steam, the results obtained may be accepted as very favourable and as fully reliable; they prove the degree of accuracy of the method employed.

Columns 16 and 17 give for each experiment the consumption of moist steam per indicated horse-power per hour. The results of all the tests without exception indicate a lower consumption when the jacket was working, and even each individual experiment with the jacket at work shows a lower consumption than any of those in which the jacket was not at work; experiment No. 2 seems the only exception, but this test, as noted in column 23, cannot be fully relied on, owing to extensive leakage which occurred at the

cylinder covers during the experiment. The utility of the steam-jacket in the locomotive engine tested, working under the conditions under which these experiments were carried out, is therefore completely demonstrated.

The total consumption of steam in lbs. per indicated horse-power per hour (Table 2, column 17) was as follows:—

Reversing lever in *second* notch. Cut-off about 30 per cent.

Steam Distribution No. I. (*See* Table 1.)

Without jacket.	*With* jacket.
34·55 lbs.	32·78 lbs.
32·14 ,,	27·69 ,,
Mean 33·34 lbs.	Mean 30·24 lbs.

Steam Distribution No. II.

	28·24 lbs.
	30·51 ,,
31·86 lbs.	28·40 ,,
30·97 ,,	30·07 ,,
31·61 ,,	28·77 ,,
Mean 31·48 lbs.	Mean 29·20 lbs.

Steam Distribution No. III.	Steam Distribution No. IV.
34·61 lbs.	29·06 lbs.
33·20 ,,	27·71 ,,
Mean 33·91 lbs.	Mean 28·38 lbs.

Steam Distribution No. V.

32·72 lbs.	
33·40 ,,	28·57 lbs.
34·97 ,,	30·16 ,,
31·92 ,,	29·98 ,,
35·03 ,,	27·09 ,,
34·33 ,,	28·88 ,,
Mean 33·73 lbs.	Mean 28·94 lbs.

Experiment No. 28 has not here been included under distribution No. V without jacket, owing to an abnormal steam consumption of 38·38 lbs. per horse-power per hour; if this were included, the mean of the tests without jacket would be 34·39 lbs. instead of 33·73 lbs.

Reversing lever in *first* notch. Cut-off about 20 per cent.

Steam Distribution No. VI.

Without jacket.	*With* jacket.
31·20 lbs.	
31·90 „	28·53 lbs.
Mean 31·55 lbs.	Mean 28·53 lbs.

Steam Distribution No. VII.

33·69 lbs.	25·07 lbs.
31·86 „	25·82 „
Mean 32·77 lbs.	Mean 25·44 lbs.

In Table 3 are grouped together all the means of these results:—

TABLE 3. *Steam Consumption* with *and* without *Steam-Jacket.*

Reversing Lever, and Cut-off.	Steam Distribution. See Table 1.	Consumption of Moist Steam per horse-power per hour.	
		Without Jacket. Lbs.	*With* Jacket. Lbs.
Second notch. Cut-off about 30 per cent.	No. I	33·34	30·24
	No. II	31·48	29·20
	No. III	33·91	—
	No. IV	—	28·38
	No. V	33·73	28·94
	Average	**33·11**	**29·19**
First notch. Cut-off about 20 per cent.	No. VI	31·55	28·53
	No. VII	32·77	25·44
	Average	**32·16**	**26·98**

From the figures given in Table 3 the following conclusions may be drawn:—

(1) Whether the steam admission or the lead be made equal at both ends of the cylinder, neither method of regulating the distribution has any perceptible influence on the consumption of steam.

(2) With the reversing lever in the second notch, giving an admission during 30 per cent. of the stroke, the working of the jacket shows an average economy of 12 per cent. in consumption of steam; and with the lever in the first notch, giving an admission during 20 per cent. of the stroke, an average economy of 16 per cent. was obtained with the jacket working.

(3) The consumption of steam per horse-power per hour with 20 per cent. admission (first notch) is from 3 to $7\frac{1}{2}$ per cent. lower than with an admission during 30 per cent. of the stroke (second notch). It must be observed however that the experiments when running in the first notch were made with a higher pressure of nearly 76 lbs. above the atmosphere; whilst during the experiments in the second notch the pressure was only about 54 lbs. The higher boiler-pressure may therefore have been the sole cause of this economy in steam consumption.

Analysis of Indicator Diagrams.

The utility of the steam-jacket having been proved, it is interesting to examine and explain the causes thereof. With this view will be selected experiments made under the same conditions of distribution, steam-pressure, and speed, with the jacket working and not working; and it will be endeavoured to ascertain the effect produced by the jacket on—

(1) The quantity of steam condensed in the cylinder during admission.

(2) The change in weight of dry steam contained in the cylinder during expansion.

For this purpose, two diagrams have been selected from amongst all those taken during each experiment, one from the front and the

other from the back of the cylinder; and these two diagrams have been accepted as average diagrams for the whole experiment, that is to say, as together representing the mean work done by the steam during one revolution of the engine. In making this choice of diagrams, those were selected which were taken when the boiler pressure and the speed were about a mean for the whole trial, and which gave a mean cylinder pressure differing as little as possible from the calculated mean pressure for the whole trial. From the large number of diagrams taken during each test, ranging from 16 to 44 diagrams from each end, it was always possible to find one which represented very nearly the conditions of the mean work of the steam during the whole trial.

The analysis of the average diagrams, selected in this way and shown in Plates 68 to 70, was made in the following manner. According to the pressure indicated by the diagram, the weight of dry steam was calculated in each end of the cylinder, front and back, at the point of cut-off, at the end of the expansion, and at the end of the compression. From these data were deduced:—(*a*) the change in weight of dry steam during expansion in each end of the cylinder separately; and (*b*) the quantity of dry steam which during the admission was added to that already contained in the clearance spaces at both ends of the cylinder. A comparison of this last quantity with the consumption of moist steam per revolution of the engine (Table 2, column 10) gave the increase during admission in the weight of the condensed water contained in the cylinder. This increase represents the sum of the quantity of water carried over into the cylinder by the moist boiler-steam, and of the quantity of steam condensed in the cylinder during admission, owing to its contact with the cylinder walls which have been cooled down during the periods of expansion and exhaust.

Some explanations are necessary respecting the details of this calculation. In order to ascertain the weight of dry steam at the point of cut-off, the pressure was estimated, not at the point of the diagram corresponding exactly with the end of the admission, as determined from the setting of the valve-motion when it was cold,

but at a point corresponding with a position of the piston a little further from the commencement of the stroke, that is to say, at a point where the form of the diagram rendered it certain that the port had really closed. Similarly, in order to estimate the pressure at the end of the expansion, a point on the diagram was taken corresponding with a position of the piston when the exhaust had not yet commenced but was just about to commence. This course was adopted in order to avoid any such errors as would have occurred if points on the diagrams had been taken where the steam port had not completely closed or where the exhaust port had already opened. Similarly, in order to estimate the weight of dry steam remaining at the end of the compression, a point was taken in the compression curve of the diagram where the admission had not yet commenced but was very near commencing.

In this way comparative analyses were made of the average diagrams from nineteen experiments, taken at random; and the results of these analyses are grouped in Table 4 on page 318, the average diagrams themselves being shown in Plates 68 to 70.

The results in this Table 4 show that the effect of the steam-jacket includes:—

(1) Chiefly a decrease in the quantity of steam condensed during admission; on the amount of this decrease depends the economy in the consumption of steam. This conclusion is confirmed by the whole of the nineteen experiments analysed, without exception, and may consequently be accepted as proved.

(2) A decrease in re-evaporation of water during expansion. With few exceptions this effect is observed in all the tests, particularly in those when running in the second notch with lower grades of expansion, and to a less extent in those when running in the first notch, that is, with higher grades of expansion.

(3) An increase of mean pressure in the cylinder. In the experiments made when working in the second notch with lower expansion this effect was less apparent, and sometimes not at all; whereas in all the experiments when working in the first notch with higher expansion it was manifest in a greater degree.

TABLE 4. *Results of analysis of Average Indicator Diagrams, Plates* 68 *to* 70.

No. of Test.	With or Without Steam-Jacket.	Mean Boiler-Pressure above atmosphere. Lbs. per square inch.	Mean Revolutions per minute.	Increase of Water inside cyl. during admission, and Water condensed in jacket; in percentage of total consumption per revolution.	Water evaporated during expansion; in percentage of weight of dry steam in cylinder at cut-off.		Consumption of Water per indicated horse-power per hour.	Mean Effective Pressure in cylinder throughout revolution. Lbs. per square inch.	Remarks.
					Back.	Front.			
No.		Lbs.	No.	Per cent.	P. c.	P. c.	Lbs.	Lbs.	
Reversing lever in *second* notch. Cut-off about 30 per cent.									
3	without	62·3	97	21	9	16	32·14	21·7	The jacket produced an economy of 14% in the consumption of steam, which is explained by the decrease of 8% in the quantity of steam condensed during admission and by the higher mean pressure in the cylinder.
4	with	64·5	102	13	4	10	27·69	24·0	
5	without	60·6	102	23	2	10	31·86	22·1	The jacket gave in test No. 7 an economy of 4%, which is explained by the decrease of 2% in the quantity of steam condensed during admission, and by the higher pressure in the cylinder. In test No. 8 the economy was 11%, which is similarly explained by the decrease of 9% in the quantity of steam condensed, and by the higher mean pressure.
7	with	60·7	101	21	4	7	30·51	22·9	
8	with	61·2	101	14	0	9	28·40	22·9	
11	without	56·0	104	19	8	14	30·97	20·6	The jacket produced an economy of 7%, arising from a decrease of 8% in the quantity of steam condensed.
10	with	56·2	100	11	3	5	28·77	20·7	
13	without	55·4	96	25	8	17	34·61	18·0	The jacket produced an economy of 16% arising from a decrease of 15% in the quantity of steam condensed.
15	with	55·1	100	10	7	13	29·06	18·3	
17	without	52·3	93	22	10	19	32·72	18·2	In tests Nos. 26 and 25 the jacket produced an economy of 12 and 17% arising from a decrease of 16 and 13% in the quantity of steam condensed, and from the higher mean pressure in test No. 25
26	with	53·2	92	6	0	6	28·88	18·5	
25	with	55·4	95	9	7	13	27·09	20·4	
28	without	48·5	91	26	15	19	38·38	15·1	The jacket produced an economy of 21% arising from a decrease of 20% in the quantity of steam condensed
23	with	47·8	96	6	−2	10	30·16	15·1	
Reversing lever in *first* notch. Cut-off about 20 per cent.									
29	without	76·4	94	28	18	42	31·20	19·8	Here also the economy produced by the jacket is explained by a decrease in the quantity of steam condensed and by the higher mean pressure in the cylinder.
34	without	75·6	92	36	11	12	33·69	18·7	
31	with	77·8	93	25	4	11	28·53	20·8	
33	with	77·8	94	23	9	10	25·82	21·6	
32	with	78·1	93	24	11	14	25·07	22·7	

Results obtained from Tests made in 1881
with an Ordinary locomotive A 21 *not steam-jacketed.*

These tests were carried out like the preceding ones on an ordinary locomotive of the same kind and of the same dimensions as the jacketed locomotive A 22 already described, from which it differed only in not having its cylinder steam-jacketed.

The verifications of the consumption of feed-water and of the moisture of the steam, although made by the methods previously described, did not attain the necessary degree of accuracy, and failed to give satisfactory results. Since in other respects the tests were carried out in the manner already described, the results will here be given of the two tests only which were perfectly complete: namely one on the 16th of September 1881 when the reversing lever was in the second notch, and another on the 21st of July 1881 with the lever in the first notch.

TABLE 5. *Test on* 16 *September* 1881; *reversing lever in* second *notch.*

Boiler Pressure above atm.	Mean Revs. per minute.	Duration of test.	Mean Effective Pressure in cylinder. Lbs. per square inch.		Consumption of Moist Steam.		Mean Indicated Horse-power.
			Back.	Front.	per revolution.	per I.H.P. per hour.	
Lbs.	Revs.	Minutes.	Lbs.	Lbs.	Lb.	Lbs.	I. H. P.
79·8	105·4	75	26·75	26·46	0·3283	29·85	69·5

Analysing the sample diagram of this test, shown in Fig. 22, Plate 71, we find:—

(*a*) During admission the quantity of water contained in the two ends of the cylinder was increased by 0·0619 lb., or 19 per cent. of the total consumption of steam per revolution.

(*b*) The quantity of water re-evaporated during expansion, compared with the quantity of dry steam present in the same end of the cylinder when the steam-port closed, was for the back end 22 per cent., and for the front 16 per cent.

TABLE 6. *Test on* 21 *July* 1881; *reversing lever in* first *notch.*

Boiler Pressure above atm.	Mean Revs. per minute.	Duration of test.	Mean Effective Pressure in cylinder. Lbs. per square inch.		Consumption of Moist Steam.		Mean Indicated Horse-power.
			Back.	Front.	per revolution.	per I.H.P. per hour.	
Lbs.	Revs.	Minutes.	Lbs.	Lbs.	Lb.	Lbs.	I. H. P.
91·4	96·9	151	24·26	26·61	0·3300	30·36	63·3

Analysing the sample diagram of this test, shown in Fig. 23, Plate 71, we find:—

(*c*) During admission the quantity of water contained in the cylinder was increased by 0·1314 lb., or 40 per cent. of the total consumption per revolution.

(*d*) The quantity of water re-evaporated during expansion was for the back end 20 per cent., and for the front 15 per cent. of the quantity of dry steam contained in the corresponding end of the cylinder when the steam-port closed.

Comparing these tests with those made without the jacket in 1882 on another engine of the same class, we find that the results obtained are generally the same, and that the conclusions drawn from the tests of 1882 are confirmed by the tests of 1881. The quantity of steam condensed during admission was the same in these two sets of tests, and this quantity was always larger when working in the first notch with earlier cut-off than when working in the second with later. In the experiments of 1881 a larger quantity of water was re-evaporated during expansion; but it must also be borne in mind that the tests of 1881 had been carried out with higher boiler-pressures of 80 and 91 lbs. above atm., as compared with 48 to 65 and 76 to 78 lbs. above atm. in those of 1882, and consequently the conditions under which the steam was working were different. This higher boiler-pressure, as well as the more regular form of the diagrams, have had much to do with the decrease of consumption per horse-power in the unjacketed experiments of 1881. This decrease however is not so considerable as that obtained *when the jacket was working* in the experiments of 1882; therefore the benefit of the jacket is further confirmed by the unjacketed experiments of 1881.

It is equally interesting to note that the working in the first notch with greater expansion in the unjacketed trials of 1881 is not more economical than the working in the second notch with less expansion. This result agrees with the third conclusion drawn from the experiments of 1882 (see page 315); in reality the tests of 1882 gave a small economy of from 3 to 7½ per cent. when changing from the second notch with 30 per cent. admission to the first notch with only 20 per cent. admission; but this result was believed to be caused by the increase of boiler-pressure from 54 up to 76 lbs. above atm.; and in the trials of 1881 this increase of pressure on changing from the second notch to the first was much less, namely from 80 up to 91 lbs. above atm. Moreover in the first notch no economy was obtained in consumption of steam, which is explained by a greater condensation during admission at the higher grades of expansion.

Turning from the indicated power to the net effective power, and bearing in mind the constant friction of the engine, it will be readily understood that the consumption of steam per effective horse-power will be larger when working in the first notch with earlier cut-off than in the second notch with later. Whence it may be concluded that cylinders of too large size are unfavourable to economy of steam.

Results obtained from Tests made in 1881 *with a Compound locomotive* A 7 *steam-jacketed.*

These tests were made with a locomotive built by Cail, and compounded according to drawings supplied by M. A. Mallet. The diameter of the small cylinder remained the same, namely 16·54 inches, the large cylinder being increased to 23·62 inches, so that the cylinder areas were very nearly as 1 to 2 (accurately 1 to 2·04); the stroke was not altered, but the valve gear was so arranged that the cut-off could be varied for each cylinder independently of the other. The slide-valves had an external lap of 0·98 inch; the valve of the small cylinder had an internal lap of negative value, that is a clearance of 0·14 inch, so as to avoid too much compression.

Both of the cylinders, as well as their covers, were steam-jacketed, similarly to the ordinary engine A 22.

The tests were made with both cylinders working, but with early cut-off and low boiler-pressure, corresponding with from 75 to 93 indicated horse-power. The mode of conducting the experiments, and their verification by means of the condensing apparatus, were the same as in the experiments of 1882 already described.

The results obtained when the jackets were not working are given in the following Table :—

TABLE 7. *Steam Consumption in Compound Engine when Steam-Jackets were* not *working.*

Date of experiment. 1881.	Distribution of Steam. Small cylinder. Notch of Reversing Lever.	Distribution of Steam. Large cylinder. Admission in percentage of stroke.	Mean Boiler Pressure above atmosphere. Lbs. per square inch.	Mean Revolutions per minute.	Duration of test.	Mean Pressure in cylinders. Small cyl.	Mean Pressure in cylinders. Large cyl.	Consumption of Moist Steam. Per rev.	Consumption of Moist Steam. Per I.H.P. per hour.	Mean Indicated Horse-power.
November	Notch.	Per cent.	Lbs.	Rev.	Min.	Lbs.	Lbs.	Lb.	Lbs.	I.H.P.
7th morning	first	60	99·2	94·2	147	21·61	6·76	0·3779	24·67	87·0
7th evening	first	60	97·3	94·5	150	20·58	7·20	0·3843	25·18	86·6
9th evening	second	46	116·7	97·1	190	19·99	8·38	0·3534	22·07	93·2

The experiments with the jackets working did not succeed, and gave very varying results in steam consumption, which was rather high compared with that when the jackets were not working. These unexpected results may be attributed either to the absence of circulation of steam by its being allowed to stagnate in the jackets, or to the imperfect draining of the condensed water, or to other defects of construction in the jackets.

The two tests made on the 7th of November were checked according to the calorimetric method already described. The degree of moisture of the steam was calculated for the first test at 6·7 per cent., and for the second test at 5·8 per cent.; part of the water in the steam must be debited to the external cooling of the steam-pipes and of the starting-valve box, etc. As both the cylinders

were at work during these tests of the compound engine, the cooling surface was greater than in the tests with the ordinary engine A 22 working with only a single cylinder; this explains the greater quantity of water found in the steam in the compound tests, and in these experiments the degree of moisture in the steam on leaving the boiler was nearly the same as that found a year later in the tests of 1882 described previously with the ordinary engine A 22.

Thus the results of the two tests on the 7th of November, agreeing with each other, may be relied on. The same however cannot be said of the test on the 9th of November, which was carried out without any calorimetric verification, and in which a large number of diagrams were failures owing to a fault of the indicator, so that the mean work done by the engine was determined only approximately; for this reason the results of this test cannot be trusted, especially in view of the consumption of steam being here too low.

The sample diagrams from the first experiment on the 7th of November are shown in Fig. 24, Plate 71. The ordinates of the diagrams from the small cylinder are here to a scale one-half of those from the large cylinder, because they were purposely taken with two different springs; that for the large cylinder was half as strong as the spring for the small cylinder.

As the position of the reversing lever in the first notch corresponded with an admission in the small cylinder of 32 per cent. in the front end and 25 per cent. in the back, and as the volume of the large cylinder was double that of the small, the apparent degree of expansion in these experiments was about seven times. The tests with the compound locomotive have therefore been made with a higher degree of expansion and with a slightly higher boiler-pressure than the trials of the ordinary locomotives.

Nevertheless, comparing the results of the tests on the compound engine on the 7th of November with those on the 21st of July and the 16th of September 1881, made on the ordinary engine A 21 with nearly the same steam-pressure (Tables 5 and 6), we find an economy of 17 per cent. in the consumption of steam by the compound locomotive.

PART II.—TRIALS MADE WITH EXPERIMENTAL TRAINS.*

As it was impossible in the testing shop to carry out experiments with high pressures of steam and late cut-off, owing to the want of a suitable friction-brake, a number of experiments were undertaken in the summer of 1883 with experimental trains, in which were used the same jacketed locomotives, compound A 7 and ordinary engine A 22, previously described, working with and without jackets alternately, and at all possible degrees of expansion and at pressures of from 118 to 132 lbs. above atmosphere.

In order to try the locomotives as far as possible under the usual conditions of work, ordinary mixed and goods trains were selected for the tests, running over the Kieff-Fastoff section of 41·10 miles length.

The experiments here described are divided into four groups:—

(*a*) Ordinary locomotive with the jackets not working.
(*b*) „ „ „ working.
(*c*) Compound locomotive with the jackets not working.
(*d*) „ „ „ working.

Each engine before being used for the experimental trains was specially overhauled, so as to avoid any accidental defects that might have impaired the proper working during the tests. The tenders of these engines were provided with two graduated water-gauge glasses, placed on the sides of the water tanks, the volume of which had previously been determined with great accuracy. The water gauge on the boiler was replaced by that shown in Figs. 8 to 10, Plate 67, having internal baffle-plates for preventing oscillations in the glass tube. The water from the overflow of the injectors was caught in small vessels of known capacity. The water condensed in the steam-jackets was discharged by means of the steam trap shown in

* The whole of this part of the paper is extracted from a detailed report by Mr. L. Loevy, assistant to the locomotive superintendent of the Russian South-Western Railways, who carried out the whole of the trials, and devised the method described of making the calculations.

Fig. 7, Plate 67, and was run into a measured tank placed underneath the engine and provided with a water-gauge glass.

Each engine was fitted with a counter so placed that it could easily be read from the cab, as well as a Klose speed-indicator, which automatically registered the speed of the engine continuously upon an endless paper ribbon. Each cylinder was provided with indicators, and seats were suitably placed for the observers who took the diagrams. The jackets were provided with pressure-gauges for showing the pressure in them at the time of taking the diagrams; and also for showing, in the tests when the jackets were not at work, whether there was any leakage.

In order to facilitate changing the papers on the indicator barrels, each experimenter had an assistant who removed the diagrams taken and replaced them with fresh papers. The diagrams and papers were passed between the experimenters and assistants by a small endless cord.

The details of the valve-motions while cold are shown in Table 8, on pages 326 and 327.

Mode of conducting the Tests.

In order that the engine might work during the whole of the test with the reversing lever in the same position, each experimental train had also a pilot engine, coupled on in front of the engine that was being tested. The pilot engine had to give out any extra power necessary for drawing the train. In consequence of the gradients however, the power given out by the locomotive under test was often too great; and it then became necessary to apply the brakes, and sometimes even to close the regulator entirely.

Six experimenters took part in the tests now described. The first controlled the positions of the regulator, as well as of the variable blast-nozzle, and took the readings of the counter, so as to know the particular revolution at which each change was made in the positions of the regulator and blast-nozzle; he also gave signals on the whistle when diagrams were to be taken. The second experimenter had to note every minute the reading of the counter and the boiler pressure. Two experimenters seated on the

TABLE 8 (*continued on opposite page*). *Details of Valve-Motions.*

Locomotive.	Right-hand Cylinder.							
	Position of Reversing Lever.	Front end.			Back end.			Travel of Valve.
		Cut-off.	Lead.	Maximum Opening of Steam Port.	Cut-off.	Lead.	Maximum Opening of Steam Port.	
	Notch.	Per cent.	Inch.	Inch.	Per cent.	Inch.	Inch.	Inches.
Ordinary Locomotive A 22.	1	21·8	?	0·331	21·5	?	0·130	?
	1	19·0	0·256	0·260	19·8	0·071	0·091	2·34
	2	28·8	0·280	0·331	28·0	0·039	0·128	2·44
	3	37·7	0·260	0·370	38·5	0·010	0·248	2·64
	5	54·2	0·201	0·436	53·8	0·030	0·501	2·95
	7	64·3	0·083	0·535	64·5	0·039	0·790	3·31
	11	78·5	−0·004	0·743	73·2	−0·030	1·073	3·82
Compound Locomotive A 7.	Large Cylinder.							
	73°	67·2	0·138	0·629	67·2	0·207	1·013	3·62
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,
	70°	64·8	0·187	0·600	65·0	0·187	0·925	3·50
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,
	60°	57·7	0·246	0·569	57·8	0·187	0·708	3·25
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,
	50°	49·8	0·310	0·541	49·8	0·167	0·541	3·09
	,,	,,	,,	,,	,,	,,	,,	,,
	,,	,,	,,	,,	,,	,,	,,	,,

Details of Valve-Motions. (*continued from opposite page*) TABLE 8.

Left-hand Cylinder.								
Position of Reversing Lever.	Front end.			Back end.			Travel of Valve.	Tests.
	Cut-off.	Lead.	Maximum Opening of Steam Port.	Cut-off.	Lead.	Maximum Opening of Steam Port.		
Notch.	Per cent.	Inch.	Inch.	Per cent.	Inch.	Inch.	Inches.	Nos.
1	22·7	?	0·295	22·3	?	0·177	?	1
1	21·7	0·266	0·276	22·2	0·069	0·118	2·36	13,15
2	32·3	0·266	0·325	31·7	0·039	0·158	2·46	16,17
3	41·8	0·246	0·364	41·5	0·020	0·276	2·64	7,8
5	57·0	0·167	0·452	56·8	0·039	0·541	2·95	9,10
7	67·5	0·069	0·570	67·0	0·059	0·836	3·35	11*b*,12*b*
11	80·5	−0·059	0·817	74·5	−0·059	1·102	3·86	11*a*,12*a*
Small Cylinder.								
1	45·3	0·285	0·442	45·6	0·049	0·335	2·66	13,14
3	60·7	0·217	0·551	60·5	0·059	0·610	3·01	15,16
5	70·5	0·089	0·600	70·5	0·039	0·885	3·35	17,18
7	77·0	−0·059	0·688	76·8	0·049	1·151	3·70	19,20
1	40·9	0·325	0·413	40·9	0·059	0·256	2·58	5,6
3	57·2	0·236	0·521	57·0	0·049	0·551	2·93	7,8
5	68·3	0·128	0·600	68·3	0·079	0·866	3·33	9,10
7	75·2	0·010	0·688	75·3	0·079	1·122	3·66	11,12
1	30·7	0·325	0·354	30·3	0·059	0·128	2·38	21,22
4	56·2	0·256	0·491	56·3	0·049	0·531	2·91	23,24
7	73·3	0·059	0·639	73·3	0·020	0·925	3·41	25,26
1	22·5	0·295	0·315	22·2	0·089	0·108	2·26	27,28
4	49·5	0·285	0·442	49·5	0·059	0·394	2·68	29,30
7	69·0	0·089	0·560	69·3	0·049	0·807	3·25	31,32

front of the locomotive took the diagrams when they received the signals; and the remaining two changed the diagram papers on the indicator drums. One of these last checked the water-levels in the tender and boiler at each station, estimated the quantity of water lost from the injector overflows, and measured the quantity of wood burnt.

Special care was taken in each test to obtain the whole of the data necessary for determining as accurately as possible the work done by the engine during the run, as well as the consumption of water and fuel. For this purpose the experimenters noted the following points during each test:—

(1) The speed of the train by means of the Klose speed-indicator.

(2) The number of revolutions of the driving wheels as shown by the counter, before starting, and at each successive minute of the run, and at each shifting of the regulator and of the variable blast-nozzle, and at each time of taking diagrams, and when the run was concluded. By this means accurate indications were obtained of the number of revolutions made during each position of the regulator and of the blast-nozzle, as well as of their positions at each moment.

(3) The boiler pressure, every minute and at each time of taking diagrams.

(4) The pressure in the steam-jackets.

(5) The mean work done in the cylinders, as measured from the indicator diagrams, which were taken with Rosenkranz indicators from both ends of the cylinders as often as possible, sometimes every minute, and whenever changes occurred either in speed or in pressure or in position of regulator or of blast-nozzle, &c.

(6) The consumption of moist steam.

(7) The consumption of wood.

(8) The quantity of steam condensed in the jackets.

Unfortunately the water-gauge glasses on the vessels that collected the condensed water from the jackets were continually getting broken, owing to the line being under repair, and the water was lost on the road. During two tests only was it possible to

estimate the quantity of water condensed in the jackets, and even then there was no certainty that the jackets had been thoroughly drained.

Calculation of Work done.

If the mean forward pressures and back-pressures in each end of each cylinder are known, and also the number of revolutions made with these mean pressures, the indicated power developed by the engine during that number of revolutions can be calculated. The mean forward pressure p in the cylinder, for the same position of the reversing lever and of the regulator, and for the same speed, depends on the absolute boiler-pressure P, and may be taken as proportional to it, that is to say $p = nP$; but the coefficient n of this proportion will vary for different speeds. The same remarks apply also to the mean back-pressures in the small cylinder of the compound engine.

By the aid of the several diagrams taken during each test, curves were drawn for each test showing for both ends of each cylinder how the percentage n varies with the number of revolutions per minute. In Figs. 25 to 30, Plate 72, are shown these curves for test No. 13 with the compound engine A 7. The curves in Figs. 25 and 26 give the percentages for the mean forward pressures in the front and back ends of the small cylinder; the curves in Figs. 27 and 28 for the mean back-pressures in the front and back ends of the small cylinder; and the curves in Figs. 29 and 30 show the percentages for the mean forward pressures in the front and back ends of the large cylinder. In all these curves the abscissæ are proportional to the number of revolutions per minute, and the ordinates give the values of the coefficient n in percentage of the absolute boiler-pressure.

As regards the mean back-pressure in the cylinders of the ordinary engine, as well as in the large cylinder of the compound engine, this does not depend, or depends in only a very small degree on the boiler pressure; but it depends on the number of revolutions per minute, and on the position of the blast-nozzle. For each test therefore, and for each position of the blast-nozzle, curves have been

drawn showing for both ends of the cylinder how the mean back-pressures vary with the number of revolutions per minute. In Figs. 31 and 32, Plate 72, are given these curves for test No. 13 when the blast-nozzle was fully open.

By the aid of all these curves can be determined, for each number of revolutions per minute and each boiler-pressure, the mean forward pressures and back-pressures in each end of each cylinder. From the speed-indicator diagram obtained separately for each test, as shown in Fig. 33, Plate 73, and from the total number of revolutions shown by the counter for the whole of the test, the number of revolutions made by the engine during periods not exceeding one minute was calculated; thence the mean number of revolutions per minute for this period; and finally the mean forward pressures and back-pressures in the cylinders corresponding with this number and with the boiler-pressures during the same period.

Having obtained these data, it was possible to calculate the amount of indicated work done by the engine during this period; and by taking the sum of all these quantities for the whole test, the total power exerted during the whole test was thus arrived at.

All this necessitated a large number of minute and complicated calculations, involving much time and labour, but enabling the power exerted to be determined very accurately.

Consumption of Water and Fuel per I.H.P. per hour.

No conclusion could be drawn from several of the trips, on account of minor accidents or partial failures. The results obtained with ordinary engine A 22 and compound A 7 in the runs which were completed satisfactorily are grouped in Table 9, pages 332–3, following the order in which the tests were made. Some indicator diagrams from the ordinary engine A 22 are shown in Plates 74 and 75, and from the compound engine A 7 in Plates 76 to 79. As seen in Table 9, the tests were made at six different positions of the reversing lever for the ordinary engine A 22, and at fourteen different positions for the compound engine A 7.

The degree of apparent expansion (neglecting the clearances), corresponding with each position of the reversing lever for each engine, is shown in column 4. The figures given for the compound engine A 7 have been estimated on the supposition that the whole expansion took place in a single cylinder having a volume equal to that of the large cylinder.

In order to be able to appreciate the effect of the degree of opening of the regulator on the loss of pressure by the steam in its passage to the steam-chest, the mean openings of the regulator for each test are given in column 15 of Table 9. From the figures in columns 14 and 15 the weight of steam passing per minute per square inch through the regulator opening has been calculated, and is given in column 16. Clearly the pressure of the steam ought to diminish in its passage from the regulator to the cylinders, and this loss ought to increase with the increase of velocity of the steam through the opening of the regulator as well as through the steam ports. As a matter of fact, on examining the diagrams from each test, it is perceived that changes of position of the regulator have produced very large losses of pressure: while the mean initial pressure in the small cylinder of the compound engine A 7 differed less than 10 per cent. from the mean boiler-pressure and averaged 95 per cent. of the latter, the mean initial pressure in the cylinders of the ordinary locomotive A 22 was 95 per cent. for tests Nos. 13 and 17; 93 per cent. for tests Nos. 8, 15, and 16; 90 per cent. for No. 1; 80 and 74 per cent. for Nos. 9, 10, and 7; 64 per cent. for No. 11*a*; 55 per cent. for No. 11*b*; and only 53 per cent. of the boiler-pressure for test No. 12*a*. It is therefore clear that only tests Nos. 13, 17, 8, 15, 16, and 1 of the ordinary engine A 22 can be compared with the tests of the compound locomotive A 7.

The figures given in column 8, Table 9, show very different weights of water evaporated per pound of wood in each test. The principal cause of these differences lies in the difficulty of measuring by eye the quantity of wood on the grate at the beginning and end of each test. In order as far as possible to compensate for this error of observation, a mean was taken of all the tests made with each engine, and it was found that the ordinary engine A 22

TABLE 9 (*continued on opposite page*). *Details of Running.*

1 Locomotive.	2 No. of Test. No.	3 Position of Reversing Lever. Notch.	4 Nominal Expansion, number of times. Times.	5 With or Without Steam-Jackets.	6 Names of Stations between which the tests were carried out.	7 Consumption of Water per indicated horse-power per hour. Lbs.
Ordinary Locomotive A 22.	1	1	4·5	without	Kieff-Fastoff	28·11
	7	3	2·5	without	,,	28·59
	8	3	2·5	with	,,	27·78
	9	5	1·8	without	,,	31·17
	10	5	1·8	with	,,	30·49
	11*a*	11	1·3	without	Kieff-Boiarka	40·37
	11*b*	7	1·5	without	Boiarka-Fastoff	35·45
	12*a*	11	1·3	with	Kieff-Boiarka	40·54
	12*b*	7	1·5	with	Boiarka-Fastoff	35·19
	13	1	4·8	without	Kieff-Fastoff	27·93
	15	1	4·8	with	,,	24·82
	16	2	3·3	without	,,	26·76
	17	2	3·3	with	,,	26·74
Compound Locomotive A 7.	5	1–70 Small cylinder. 1–60 Large cylinder.	5·0	without	Kieff-Fastoff	22·62
	6	1–70	5·0	with	Fastoff-Kieff	22·31
	7	3–70	3·6	without	Kieff-Fastoff	23·77
	8	3–70	3·6	with	Fastoff-Kieff	23·17
	9	5–70	3·0	without	Kieff-Fastoff	23·90
	10	5–70	3·0	with	Fastoff-Kieff	25·09
	11	7–70	2·7	without	Kieff-Fastoff	24·69
	12	7–70	2·7	with	Fastoff-Kieff	24·23
	13	1–73	4·5	without	Kieff-Fastoff	22·07
	14	1–73	4·5	with	Motovilowka-Kieff	24·71
	15	3–73	3·4	without	Kieff-Fastoff	22·69
	16	3–73	3·4	with	Fastoff-Kieff	26·15
	17	5–73	2·9	without	Kieff-Fastoff	24·58
	18	5–73	2·9	with	Motovilowka-Kieff	25·24
	19	7–73	2·7	without	Kieff-Fastoff	25·24
	20	7–73	2·7	with	Fastoff-Kieff	27·93
	21	1–60	6·7	without	Kieff-Fastoff	19·95
	22	1–60	6·7	with	Fastoff-Kieff	23·21
	23	4–60	3·6	without	Kieff-Fastoff	22·16
	24	4–60	3·6	with	Fastoff-Kieff	25·44
	25	7–60	2·8	without	Kieff-Fastoff	23·88
	26	7–60	2·8	with	Fastoff-Kieff	25·53
	27	1–50	9·1	without	Kieff-Fastoff	23·68
	29	4–50	4·1	without	,,	23·28
	30	4–50	4·1	with	Fastoff-Kieff	25·20
	31	7–50	3·0	without	Kieff-Fastoff	23·70
	32	7–50	3·0	with	Fastoff-Kieff	25·46

Details of Running. (*continued from opposite page*) TABLE 9.

8	9	10	11	12	3	14	15	16
Water Evaporated per pound of wood.	Consumption of Wood per Indicated horse-power per hour.	Duration of test.	Mean Revolutions per minute.	Mean Boiler-Pressure above atm. Lbs. per square inch.	Mean Indicated Horse-Power.	Mean Consumption of Moist Steam per hour.	Approximate Mean Opening of Regulator.	Weight of Steam passing per minute per square inch through regulator.
		Whilst the engine was running (regulator open).						
Lbs.	Lbs.	Minutes.	Revs.	Lbs.	I. H. P.	Lbs.	Sq. Inch.	Lbs.
3·25	8·64	121·5	76	127·5	164	4612	0·445	172
3·79	7·54	95·5	79	121·8	226	6453	0·268	401
3·56	7·80	95	79	114·7	248	6896	0·998	115
3·28	9·50	96·5	83	119·0	272	8475	0·691	205
3·17	9·63	100·5	83	100·5	257	7851	0·626	209
3·20	12·61	49	62	116·2	190	7687	0·205	626
	11·07	72	80	123·3	241	8543	0·202	701
3·10	13·10	33·5	91	121·8	230	9319	0·129	1208
	11·38	57·5	99	123·3	279	9821	0·353	464
3·39	8·25	118	87	121·8	187	5247	1·356	64
2·90	8·55	102·5	92	126·1	200	4967	0·890	92
3·74	7·10	123·5	71	121·8	209	5593	1·076	98
3·64	7·36	112·5	74	116·2	215	5750	1·928	50
3·23	7·01	95	90	127·5	172	3882	15·742	4
3·05	7·32	84·5	99	117·6	198	4416	17·148	4
3·78	6·28	91	95	123·3	216	5124	12·355	7
4·04	5·73	77	104	129·0	253	5871	16·291	6
3·51	6·81	92	92	126·8	245	5860	10·579	9
4·15	6·04	78	92	121·1	226	5661	10·284	9
3·59	6·88	84	90	122·6	259	6409	11·064	10
4·06	5·97	69·5	107	126·8	307	7452	15·114	9
4·04	5·47	111	79	129·7	172	3785	15·502	4
4·10	6·02	65	104	117·6	168	4147	6·323	11
3·65	6·22	106·5	87	131·1	235	5326	14·607	6
4·40	5·93	68	88	113·3	157	4118	4·475	16
4·01	6·13	100	88	123·3	239	5869	10·502	9
4·01	6·28	57	102	124·7	277	7006	14·191	9
3·64	6·94	77·5	112	121·8	323	8153	13·913	10
4·23	6·61	60	115	107·6	273	7641	9·260	14
3·95	5·05	109·5	86	127·5	135	2687	14·144	3
3·56	6·53	80	99	123·3	128	2965	15·077	3
3·76	5·89	97	85	120·4	195	4330	11·413	6
4·33	5·89	75·5	81	111·2	164	4178	6·809	10
3·77	6·33	82	98	123·3	261	6226	13·713	7
4·42	5·78	71	94	112·6	229	5860	12·090	9
3·62	6·50	135	78	133·2	85	2022	17·725	1
3·66	6·37	110	84	124·0	160	3737	15·624	4
4·45	5·67	72·5	102	114·0	161	4063	14·119	4
3·30	7·19	94	91	131·1	216	5128	8·003	11
3·99	6·39	80	92	121·8	229	5836	12·910	7

evaporated 3·33 lbs. of water per pound of wood, and the compound engine A 7 evaporated 3·82 lbs.; that is to say, the compound engine A 7 evaporated 14·6 per cent. more water per pound of wood.* These mean figures have been used in the following calculations.

Comparative Consumption of Water and Fuel in Compound and Ordinary locomotives expanding equally.

In Table 10, pages 336–7, are given the results of the tests, following the order of decreasing expansion.

An examination of this Table shows that only tests Nos. 1, 13, 15, 16, and 17, made in the first and second notch with the ordinary engine A 22, come within the limits of expansion employed in the compound engine A 7. Moreover for tests Nos. 13, 15, 16, and 17, of the ordinary engine A 22, there are no tests of the compound engine A 7 carried out with exactly corresponding expansion; so that, in order to make exact comparisons, it is necessary to find the consumptions of water and fuel in the compound engine A 7 for expansions equal to those which took place during tests Nos. 13 and 16.

On account of causes which are described further on (pp. 343–5), the comparisons will only be made between tests carried out when the jackets were not at work. The tests without jackets on the compound engine A 7 were made with average boiler-pressures very slightly varying, and ranging from 120 to 133 lbs. per square inch above atmosphere; that is to say, within nearly the same limits as tests Nos. 13, 16, and 1, with the ordinary engine A 22. The slight variations of pressure in these tests may therefore be neglected. On the other hand the speed (average number of revolutions per minute) varies considerably for the compound A 7 and ordinary engine A 22. Comparing test No. 7 with No. 23, and test No. 11 with No. 19, carried out on the compound engine A 7 with a nearly equal pressure but at a different speed, we find greater consumptions at higher speeds. It may therefore be admitted that the consumptions of

* Part of this result to the credit of the compound engine A 7 may be attributed to the stoker's care, as well as to the want of uniformity in the wood used.

steam in the ordinary engine A 22 are less than they would have been if the mean speed had been as high as in the tests of the compound engine A 7.

Taking two rectangular co-ordinates, Fig. 34, Plate 73, and laying off on the abscissa lengths proportional to the degree of expansion, and on the corresponding ordinates lengths proportional to the consumption of water in lbs. per indicated horse-power per hour, as ascertained in each test of the compound engine, a series of points are obtained which are marked in the diagram with the numbers of the tests, and through which is drawn a curve representing with sufficient accuracy for the compound engine how the consumption of water varies with the degree of expansion. For an expansion of 4·8 times, corresponding with test No. 13 of the ordinary engine A 22, this curve gives a consumption of 21·83 lbs. of water for the compound engine; and for an expansion of 3·3 times, corresponding with test No. 16 of the ordinary engine A 22, a consumption of 23·15 lbs. Comparing these figures with the corresponding figures of the consumption in the ordinary engine A 22 (for test No. 13 = 27·93, and for test No. 16 = 26·76 lbs.), it is seen that the compound engine, in comparison with the ordinary engine A 22, gives with 4·8 times expansion an economy of 22 per cent., and with 3·3 times expansion an economy of 13 per cent. in consumption of steam per indicated horse-power.

Comparing test No. 13 of the compound engine with test No. 1 of the ordinary engine A 22 carried out with the same expansion of 4·5 times, the compound engine shows an economy of 21 per cent. in consumption of steam.

If the curve in Fig. 34, Plate 73, be continued towards the left, as shown dotted, it is found that the consumption of steam with an expansion of 2·5 times will be about 26·23 lbs. for the compound engine. Comparing this consumption with that in test No. 7 of the ordinary engine A 22, namely 28·59 lbs., there is found an economy of 9 per cent. for the compound engine.

Turning from the consumption of water to the consumption of fuel per indicated horse-power per hour, and bearing in mind that the mean evaporation in the ordinary engine A 22 was 3·33 lbs.

TABLE 10 (*continued on opposite page*). *Water Consumption in Ordinary*

Nominal Expansion, number of times.	Ordinary Locomotive A 22.								
	Without jackets.				With jackets.				Economy produced by Jackets, percentage of consumption of steam without jackets.
	No. of Test.	Mean Boiler-Pressure above atmosphere. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water per I.H.P. per hour.	No. of Test.	Mean Boiler-Pressure above atmosphere. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water per I.H.P. per hour.	
Times.	No.	Lbs.	Revs.	Lbs.	No.	Lbs.	Revs.	Lbs.	Per cent.
9·1	..	..	..	..	..	..	..	..	..
6·7	..	..	..	..	..	..	..	..	..
5·0	..	..	..	..	..	..	..	..	..
4·8	13	121·8	87	27·93	15	126·1	92	24·82	+ 11·9
4·5	1	127·5	76	28·11	..	..	..	..	..
4·1	..	..	..	..	..	..	..	..	..
3·6	..	..	..	..	..	..	..	..	..
3·4	..	..	..	..	..	..	..	..	..
3·3	16	121·8	71	26·76	17	116·2	74	26·74	+ 0·07
3·0	..	..	..	..	..	..	..	..	..
2·9	..	..	..	..	..	..	..	..	..
2·8	..	..	..	..	..	..	..	..	..
2·7	..	..	..	..	..	..	..	..	..
2·5	7	121·8	79	28·59	8	114·7	79	27·78	+ 2·8
1·8	9	119·0	83	31·17	10	100·5	83	30·49	+ 2·2
1·5	11*b*	123·3	80	35·45	12*b*	123·3	99	35·19	+ 0·7
1·3	11*a*	116·2	62	40·37	12*a*	121·8	91	40·54	− 0·4

and Compound Locomotive. (*continued from opposite page*) TABLE 10.

Nominal Expansion, number of times.	Compound Locomotive A 7.								
	Without jackets.				With jackets.				Economy produced by Jackets, percentage of consumption of steam without jackets.
	No. of Test.	Mean Boiler-Pressure above atmosphere. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water per I.H.P. per hour.	No. of Test.	Mean Boiler-Pressure above atmosphere. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water per I.H.P. per hour.	
Times.	No.	Lbs.	Revs.	Lbs.	No.	Lbs.	Revs.	Lbs.	Per cent.
9·1	27	133·2	78	23·68	..	..	..	..	..
6·7	21	127·5	86	19·95	22	123·3	99	23·21	−16·4
5·0	5	127·5	90	22·62	6	117·6	99	22·31	+ 1·3
4·8	..	..	..	..	..	..	..	..	..
4·5	13	129·7	79	22·07	14	117·6	104	24·71	−12·0
4·1	29	124·0	84	23·28	30	114·0	102	25·20	− 8·3
3·6	7	123·3	95	23·77	8	129·0	104	23·17	+ 2·4
	23	120·4	85	22·16	24	111·2	81	25·44	−14·8
3·4	15	131·1	87	22·69	16	113·3	88	26·15	−15·2
3·3	..	..	..	..	..	..	..	..	..
3·0	9	126·8	92	23·90	10	121·1	92	25·09	− 5·0
	31	131·1	91	23·70	32	121·8	92	25·46	− 7·4
2·9	17	123·3	88	24·58	18	124·7	102	25·24	− 2·8
2·8	25	123·3	98	23·88	26	112·6	94	25·53	− 6·9
2·7	11	122·6	90	24·69	12	126·8	107	24·23	+ 1·9
	19	121·8	112	25·24	20	107·6	115	27·93	−10·7
2·5	..	..	..	..	..	..	..	..	..
1·8	..	..	..	..	..	..	..	..	..
1·5	..	..	..	..	..	..	..	..	..
1·3	..	..	..	..	..	..	..	..	..

per pound of wood, and in the compound engine 3·82 lbs., we find for the compound engine, as compared with the ordinary, the following economy in consumption of fuel :—

with	4·8	times expansion	32	per cent.
„	4·5	„ „	31	„
„	3·3	„ „	23	„
„	2·5	„ „	20	„

The examination of all these data leads therefore to the following conclusions :—

(1) With the same expansion of steam, the consumption of water and fuel per indicated horse-power is less in the compound than in the ordinary locomotive.

(2) The economy of water and fuel in the compound locomotive, under the same conditions of expansion, is greater according as the range of expansion is higher.

(3) With 4·8 times expansion, the highest that could be obtained in the ordinary locomotive A 22, the compound engine gave an economy of 22 per cent. in steam and of 32 per cent. in fuel.

Comparative Work done by Compound and Ordinary locomotives with equal consumption of water and fuel.

In order to be able to compare the work done by the same two engines on an equal consumption of water and fuel, a series of tests must be selected that were made with the same average boiler-pressure and the same mean number of revolutions per minute. In Table 11 are given the results of tests in which the pressures and speeds were nearly equal.

Analysing the data contained in this Table in a similar manner to the preceding Table 10, it is found :—

(1) For an equal consumption of 5247 lbs. of water per hour, the compound engine developed 222 horse-power, or 19 per cent. more than the ordinary engine A 22, which developed 187 horse-power.

(2) For an equal consumption of 5593 lbs. of water per hour, the difference in the work developed was 11 per cent. in favour of the compound engine.

TABLE 11.

Ordinary Locomotive A 22.					Compound Locomotive A 7.				
No. of Test.	Mean Boiler-Pressure above atm. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water.		No. of Test.	Mean Boiler-Pressure above atm. Lbs. per sq. inch.	Mean Revolutions per minute.	Consumption of Water.	
			Per hour.	Per I. H. P. per hour.				Per hour.	Per I. H. P. per hour.
No.	Lbs.	Revs.	Lbs.	Lbs.	No.	Lbs.	Revs.	Lbs.	Lbs.
					29	124·0	84	3737	23·28
					23	120·4	85	4330	22·16
13	121·8	87	5247	27·93					
16	121·8	71	5593	26·76					
					17	123·3	88	5869	24·58
					11	122·6	90	6469	24·69

(3) For an equal consumption of $\frac{5247}{3 \cdot 33} = 1574$ lbs. of wood per hour, the compound engine developed 246 horse-power, or 32 per cent. more than the ordinary engine A 22, which developed 187 horse-power.

(4) For a consumption of $\frac{5593}{3 \cdot 33} = 1678$ lbs. of wood per hour, the difference was still 24 per cent. in favour of the compound.

We therefore arrive at the following conclusions:—

(1) For the same consumption of water and fuel per hour, the work done by the compound engine is greater than that done by the ordinary engine.

(2) For the same boiler-pressure and the same speed, the increase of work done by the compound engine compared with the ordinary engine diminishes in proportion as the total consumption of water and fuel per hour increases.

(3) For an equal consumption of 5247 lbs. of water per hour, with a boiler-pressure of 122 lbs. above atmosphere, and a speed of 87 revolutions per minute, the work done by the compound engine is 19 per cent. greater than that done by the ordinary engine.

(4) Under the same conditions, and for an equal consumption of 1574 lbs. of wood per hour, the work done by the compound engine is 32 per cent. greater than that done by the ordinary engine.

Comparative Consumption of Water and Fuel in Compound and Ordinary locomotives doing equal work.

The same tests may be taken for comparing the consumption of water and fuel in doing the same amount of work. All the necessary data from these tests are given in Table 12.

TABLE 12.

Ordinary Locomotive A 22.					Compound Locomotive A 7.				
No. of Test.	Mean Boiler-Pressure above atm. Lbs. per sq. inch.	Mean Revolutions per minute.	Mean Indicated Horse-power.	Water consumed per I.H.P. per hour.	No. of Test.	Mean Boiler-Pressure above atm. Lbs. per sq. inch.	Mean Revolutions per minute.	Mean Indicated Horse-power.	Water consumed per I.H.P. per hour.
No.	Lbs.	Revs.	I.H.P.	Lbs.	No.	Lbs.	Revs.	I.H.P.	Lbs.
					29	124·0	84	160	23·28
13	121·8	87	187	27·93					
					23	120·4	85	195	22·16
16	121·8	71	209	26·76					
					17	123·3	88	239	24·58
					11	122·6	90	259	24·69

As it is impossible to make a direct comparison of the figures in this Table, a curve has here again to be drawn, as represented in Fig. 35, Plate 73, showing for the compound engine how the consumption of water per indicated horse-power per hour varies with the quantity of work done at the same boiler-pressure of about 122 lbs. above atmosphere in this instance, and at the same speed of about 87 revolutions per minute. Test No. 13 of the ordinary engine A 22 is the only one which allows an accurate comparison to be made with the tests of the compound engine. Test No. 16, made

with a smaller number of revolutions per minute than the preceding test, can furnish only approximate results.

From the curve in Fig. 35, Plate 73, it is found that the compound engine, when indicating 187 horse-power, consumes under the above conditions 22·71 lbs. of water per horse-power per hour. For the same work the ordinary engine A 22 consumes 27·93 lbs. per horse-power per hour, thus showing an economy of 19 per cent. in favour of the compound engine. Similarly when developing 209 horse-power the economy in consumption of water is 13 per cent. in favour of the compound engine.

The economy in consumption of fuel at 187 horse-power is 29 per cent., and at 209 horse-power 24 per cent. From this we conclude:—

(1) For doing the same work the compound engine uses less water and less fuel than the ordinary engine.

(2) At the same boiler-pressure and the same speed, the economy diminishes with the increase of work done.

(3) With a boiler-pressure of about 122 lbs. above atmosphere, and a mean speed of 87 revolutions per minute, and when developing 187 horse-power, the compound engine gives an economy over the ordinary engine of 19 per cent. in consumption of water and 29 per cent. in fuel.

Proportion of Work done in Small and Large Cylinder of Compound locomotive.

In describing the calculations of the work done by the engines, it has been explained that, for each test, curves were plotted for showing approximately how the mean cylinder-pressure varied with the number of revolutions per minute. From these curves has been calculated the work done separately by each cylinder of the compound engine at boiler-pressures of 113, 120, and 127 lbs. per square inch above atmosphere, and at speeds of 50, 100, and 150 revolutions per minute. In this way for each test the relation has been calculated between the work done in the small and the large cylinder separately. The values of these ratios are given in Table 13, page 342.

TABLE 13.

Work done in Small and Large Cylinder of Compound Locomotive.

Cut-off. Per cent.		Nominal Expansion, number of times.	No. of Test.	Ratio of Work done in Small cylinder, to Work done in Large cylinder taken as unity.								
				Boiler Pressure above atmosphere. Lbs. per square inch.								
				113 lbs.			120 lbs.			127 lbs.		
				Revs. per minute.			Revs. per minute.			Revs. per minute.		
Small cylinder. P. c.	Large cylinder. P. c.	Times.	No.	50	100	150	50	100	150	50	100	150
45·5	67·2	4·5	13	1·41	1·40	1·37	1·31	1·28	1·25	1·22	1·18	1·14
,,	,,	,,	14	0·96	1·18	1·11	0·91	1·09	1·00	0·89	1·05	0·91
60·6	,,	3·4	15	0·98	0·93	0·91	0·96	0·87	0·83	0·91	0·85	0·79
,,	,,	,,	16	0·83	0·75	—	0·81	0·72	—	0·78	0·70	—
70·5	,,	2·9	17	0·72	0·72	0·67	0·70	0·71	0·64	0·69	0·67	0·61
,,	,,	,,	18	0·70	0·70	0·53	0·67	0·62	0·51	0·67	0·59	0·50
76·9	,,	2·7	19	0·56	0·53	0·49	0·55	0·52	0·47	0·54	0·51	0·45
,,	,,	,,	20	0·55	0·47	0·41	0·53	0·45	0·39	0·53	0·45	0·38
40·9	64·9	5·0	5	1·29	1·47	1·31	1·19	1·37	1·17	1·15	1·26	1·17
,,	,,	,,	6	0·99	1·13	1·43	0·94	1·04	1·27	0·91	0·96	1·19
57·1	,,	3·6	7	0·94	0·98	0·54	0·89	0·92	0·54	0·85	0·89	0·48
,,	,,	,,	8	0·85	0·80	0·77	0·83	0·78	0·73	0·78	0·74	0·73
68·3	,,	3·0	9	0·68	0·65	0·56	0·67	0·62	0·53	0·66	0·61	0·50
,,	,,	,,	10	0·70	0·66	0·38	0·67	0·57	0·36	0·65	0·54	0·35
75·2	,,	2·7	11	0·61	0·49	0·34	0·57	0·48	0·33	0·59	0·47	0·32
,,	,,	,,	12	0·53	0·51	0·44	0·51	0·49	0·43	0·51	0·47	0·41
30·5	57·8	6·7	21	1·49	1·50	2·07	1·42	1·32	1·74	1·24	1·32	1·55
,,	,,	,,	22	1·13	1·19	1·41	1·08	1·06	1·15	1·03	1·01	0·98
56·3	,,	3·6	23	0·85	0·71	0·51	0·81	0·67	0·49	0·77	0·64	0·46
,,	,,	,,	24	0·63	0·55	—	0·62	0·52	—	0·68	0·50	—
73·3	,,	2·8	25	0·56	0·47	0·37	0·54	0·45	0·35	0·54	0·45	0·34
,,	,,	,,	26	0·49	0·37	0·32	0·48	0·35	0·31	0·48	0·35	0·29
49·5	49·8	4·1	29	0·87	0·71	0·53	0·82	0·68	0·49	0·77	0·64	0·45
,,	,,	,,	30	0·75	0·60	0·47	0·71	0·56	0·43	0·68	0·53	0·45
69·2	,,	3·0	31	0·45	0·39	—	0·43	0·38	—	0·43	0·35	—
,,	,,	,,	32	0·51	0·36	—	0·49	0·36	—	0·47	0·35	—

An examination of the figures in this Table 13 shows :—

(1) For the same boiler-pressure and the same number of revolutions, the proportion of work done in the small and the large cylinder varies according to the cut-off in the respective cylinders.

(2) For the same boiler-pressure, the same number of revolutions, and the same cut-off in the large cylinder, the proportionate work done in the small cylinder decreases as the admission into the small cylinder increases.

The proportion of work done in the small and the large cylinder varies with the speed when the boiler-pressure remains the same, and with the pressure when the speed remains the same.

It is therefore altogether impossible to arrive at any fixed combinations of cut-off in the two cylinders whereby the work developed shall be equalised in both cylinders for all speeds and all pressures that occur in running.

Effect of Jackets on Consumption of Steam.

In Table 10, pages 336–7, is given the ascertained consumption of steam per indicated horse-power per hour for the tests with and without jackets, including the steam used in the jackets themselves.

Comparing the consumption of water per indicated horse-power per hour with and without jackets, in the tests made with equal degrees of expansion, the economy produced by the jackets has been calculated in corresponding columns in Table 10, where the plus sign + shows an economy in favour of the jackets, and the minus sign — an increase in consumption of steam when the jackets were used.

The examination of these columns shows for the ordinary engine A 22, when working with the highest expansion of 4·8 times in the first notch, an economy of 12 per cent. in favour of the jackets. With 3·3 times expansion in the second notch, the effect of the jackets disappears ; with 2·5 times expansion, the economy from the use of the jackets is 3 per cent. ; and for lower degrees of expansion it gradually decreases to nothing, and even becomes negative when the expansion is only 1·3 times.

The entire failure of the attempts to measure the quantity of water condensed in the jackets, as well as the impossibility of

selecting an average diagram representing with sufficient accuracy the mean work of the steam in the cylinders during the whole of the test, rendered it hopeless to estimate the effect which the jackets had upon the condition of the steam in the cylinders.

In order to avoid loss of steam through the apparatus for draining the jackets, it was necessary to open the cock but slightly; and thus an imperfect discharge of the condensed water may have been the result.

It must be noted however that in these tests the effect of the steam-jackets is much less than in those carried out in the testing shed. To a certain extent this may be explained by the expenditure of steam at each opening of the regulator for warming the jackets, and by the unprofitable condensation of the steam remaining in them at each closing of the regulator; these losses did not take place during the experiments made in the testing shed. Also the probably imperfect draining of the jackets would not be without influence on their effect.

Passing on to the tests of the compound engine in Table 10, it must be observed in the first place that the consumption of steam in the tests made when the jackets were at work must up to a certain point be greater than in the tests made when they were not at work, in consequence of the higher mean speed of running when the jackets were working. Nevertheless the negative results given by the jackets cannot be disputed. This altogether unexpected result may to a certain extent be explained by peculiarities in the construction of the compound engine, and by the conditions under which it worked.

Foremost must be noted the advantageous position of the intermediate receiver placed inside the hot smoke-box, where the temperature rises to 570° Fahr. and upwards. The steam in its passage from the small to the large cylinder thus encounters a new and abundant source of heat, and is heated up to a certain point (perhaps even superheated), and in this state enters the large cylinder to continue its work. The compound locomotive therefore works under more advantageous conditions than a compound stationary engine, in which the intermediate receiver is not heated

or is only a little heated; consequently the useful effect of the jackets should be less in a compound locomotive than in a compound stationary engine.

Moreover in a compound locomotive with steam-jacketed cylinders, like the compound A 7, the loss of steam in heating the cylinders and jackets at each opening and closing of the regulator will be greater than in an ordinary locomotive, owing to the large volume of the cylinders and jackets; but as the consumption of steam per horse-power per hour is less in the compound locomotive, it follows that the expenditure of steam for working the jackets in the compound engine is relatively greater than in an ordinary locomotive. These circumstances, to which must be added the probably imperfect draining of the condensed water, have led to the negative results given by the jackets of the compound engine.

Experiments made in 1881–82 *with Compound and Ordinary locomotives while running.*

Prior to the tests already described, and soon after the first engine had been altered to the compound system in 1881–82, a number of experimental runs were made with the ordinary engine A 22 and the compound A 7. These runs were made during the ordinary working of these engines when taking the mail trains between Kieff, Fastoff, and Kasatine, a distance of 97 miles. During the trip the engine worked with different degrees of cut-off in the cylinders; and the compound engine at starting made a few revolutions with boiler steam admitted direct into both cylinders.

The method adopted in these tests did not differ at all from that employed in the tests subsequently carried out with the same engines in 1883, pages 324–328. The results obtained are grouped together in Table 14 on page 346.

The following approximate conclusions are arrived at from this Table:—

(1) When the jackets are not in use, the compound engine gives in comparison with the ordinary engine an economy of 13 per cent. in consumption of steam, and of 24 per cent. in consumption of wood.

TABLE 14.

Locomotive.	Date of Test.	Names of Stations between which the tests were carried out.	Mean Expansion, number of times.	Mean Boiler-Pressure above atmosphere. Lbs. per square inch.	Mean Revolutions per minute.	Consumption per I.H.P. per hour.				With or Without Steam-Jackets.
						Water.	Wood.	Mean. Water.	Mean. Wood.	
	1881.		No.	Lbs.	Revs.	Lbs.	Lbs.	Lbs.	Lbs.	
Ordinary A 22.	29 Sep.	Kieff-Fastoff	3·2	123·3	116	30·0	9·52	29·5	9·38	without
	,,	Fastoff-Kasatine	3·4	121·8	140	29·1	9·24			
	3 Oct.	Kieff-Fastoff	3·3	123·3	95	29·8	9·99	29·5	9·91	with
	,,	Fastoff-Kasatine	3·3	121·8	133	29·3	9·83			
	1882.									
Compound A 7.	4 Mar.	Kieff-Fastoff	3·4	126·1	103	25·1	6·77	25·6	7·14	without
	6 ,,	Fastoff-Kasatine	3·0	119·0	126	26·2	7·52			
	6 ,,	Kieff-Fastoff	3·1	127·5	114	27·8	7·96	28·4	7·88	with
	4 ,,	Fastoff-Kasatine	3·2	120·4	135	29·1	7·80			

(2) Admission of steam into the jackets does not sensibly affect the consumption of steam in the ordinary engine; whilst in the compound engine it produces an injurious effect, increasing the consumption of water and wood per indicated horse-power.

These conclusions accordingly agree with those derived from the tests subsequently carried out in 1883 and already described in the foregoing pages 324–345.

PART III.—Consumption of Fuel in Compound locomotive, and in Ordinary engines of same class, during regular work at Kasatine.

The ordinary work of a locomotive in service depends on such a number of different circumstances, which occur on the road and are of a nature to produce disturbing influences, that it is very difficult or almost impossible to arrive at any accurate conclusion concerning the result of the ordinary work done by the engines when running. Nevertheless, after five years' regular work of the compound engine A 7, it is interesting to compare the data thus obtained as to the consumption of fuel in this engine and in the other ordinary engines of the same class A, during their work at Kasatine under conditions more or less identical.

This comparison shows that, during the period 1881–1885 inclusive, the mean consumption of wood was as given in Table 15:—

TABLE 15. *Mean Consumption of Wood during five years.*

	By the Ordinary engines of class A.	By the Compound engine A 7.	Economy in favour of Compound engine.
	Cubic Feet.	Cubic Feet.	Per cent.
Per 1000 engine-miles	2649	2244	15
Per 1000 axle-miles run by wagons	109	82	25

Thus according to the returns the economy shown by the compound engine in consumption of fuel during the five years 1881–1885 ranges between 15 and 25 per cent. It may be added that the returns also show that the compound engine worked during each year more economically than any other engine of the same class at Kasatine.

TABLE 16. *Consumption of Steam in Ordinary and Compound Locomotives without Steam-Jackets.*

Ordinary Locomotives A 21 and A 22.						Compound Locomotive A 7.		
Reversing Lever in *second* notch. Nominal Expansion 3·3 times.			Reversing Lever in *first* notch. Nominal Expansion 4·5 to 5·0 times.			Reversing Lever :— Small cyl. *first* notch. Large cyl. 60°. Nominal Expansion 6·7 times.		
Boiler-Pressure above atm. Lbs. per sq. inch.	Consumption of Steam per I. H. P. per hour.	Experimental Train, or Testing Shed. Year.* Engine A 21 or A 22.	Boiler-Pressure above atm. Lbs. per sq. inch.	Consumption of Steam per I. H. P. per hour.	Experimental Train, or Testing Shed. Year.* Engine A 21 or A 22.	Boiler-Pressure above atm. Lbs. per sq. inch.	Consumption of Steam per I. H. P. per hour.	Experimental Train, or Testing Shed. Year.†
Lbs.	Lbs.		Lbs.	Lbs.		Lbs.	Lbs.	
121·8	26·76	Train 1883. A 22	127·5	28·11	Train 1883. A 22	127·5	19·95	Train 1883.
79·8	29·85	Shed 1881. A 21	121·8	27·93		99·2	24·67	Shed 1881.
62·3	32·14		91·4	30·36	Shed 1881. A 21	97·3	25·18	
60·6	31 86		76·4	31·20				
56·0	30·97		76·7	31·90	Shed 1882. A 22			
55·3	31·61		75·0	31·86				
55·4	34·61		75·6	33·69				
54·4	33·20	Shed 1882. A 22						
52·3	32·72							
51·6	33·40							
51·3	34·33							
50·6	34·97							
45·0	35·03							

* For tests in 1881 see Tables 5 and 6.
,, 1882 ,, Table 2.
,, 1883 ,, Table 9.

† For tests in 1881 see Table 7.
,, 1883 ,, Table 9.

PART IV.—General Conclusions.

(1) Comparing the consumption of steam per horse-power, as arrived at by altogether different methods in the testing shed and when running with experimental trains, Table 16 is obtained, page 348, for the working without steam-jackets and with the same degree of expansion.

As here seen, the results obtained from the trials made in the testing shed and with the experimental trains, by altogether different methods, during different years, and with different engines of the same class, agree with one another, and prove that the consumption of steam per horse-power in all the tests increases regularly as the boiler-pressure diminishes.

The results of the tests carried out with the jackets at work are not here referred to, because in the experimental trains, as already stated, the jackets did not work properly.

(2) Comparing the consumption of steam per indicated horse-power at different degrees of expansion, obtained with the ordinary engine A 22 when working without jackets in the experimental trains, as given in Table 9, the following Table 17 is compiled :—

TABLE 17. *Ordinary Locomotive* A 22 *without Steam-Jackets.*

Position of Reversing Lever. Notch.	Nominal Expansion. Times.	Consumption of Water per I. H.P. per hour. Lbs.
1	4·8	{ 27·93 28·11
2	3·3	26·76
3	2·5	28·59
5	1·8	31·17
7	1·5	35·45
11	1·3	40·37

As here seen, the work done by the steam when running in the first notch is not only not more advantageous, but is even less economical than when working in the second notch with a lower expansion: this conclusion is confirmed by the results obtained in the testing shed in 1882 and 1881 (pages 315 and 321). The consumption per indicated horse-power in the third notch, expanding about 2·5 times, is hardly greater than when working in the first notch, expanding nearly 5 times. Thus the conclusion arrived at on page 321 is confirmed by all the tests, namely that it is disadvantageous to use cylinders of too large size. The work done in the seventh and eleventh notches, with 1·5 and 1·3 times expansion, is seen to be attended with very little economy; but it must not be forgotten that these latter tests were made with the regulator only slightly open, whereby the free passage of the steam into the cylinders was obstructed (see page 331).

(3) In Table 18, page 351, is given a similar comparison of the consumption of steam in the compound engine at different degrees of expansion and without steam-jackets, the figures being compiled from Table 9.

For all the positions (73°, 70°, 60°, and 50°) of the reversing screw of the large cylinder, a regular though slow increase is observed in the consumption of steam per horse-power, according as the degree of expansion decreases between the limits of 6·7 and 2·7 times.* This difference from what took place with the ordinary engine A 22 is explained if it be remembered that in the compound engine the condensation of steam during admission is comparatively less, and consequently this condensation does not produce such a bad effect on the total consumption of steam at an early cut-off or high degree of expansion as it does in ordinary engines.

Comparing the consumption of steam at different positions of the reversing screw of the large cylinder, it is found that, with the same degree of expansion, the lowest consumption took place with the screw at 60°, corresponding with an admission into the large cylinder

* In the test in which the position of the reversing lever was 1–50°, it appears that the expansion was carried too far, namely 9·1 times.

TABLE 18. *Compound Locomotive without Steam-Jackets.*

Position of Reversing Lever.		Nominal Expansion, number of times.	Steam Consumption per indicated horse-power per hour.	Position of Reversing Lever.		Nominal Expansion, number of times.	Steam Consumption per indicated horse-power per hour.
Small cylinder.	Large cylinder.			Small cylinder.	Large cylinder.		
Notch.		Times.	Lbs.	Notch.		Times.	Lbs.
1	73°	4·5	22·07	1	60°	6·7	19·95
3	73°	3·4	22·69	4	60°	3·6	22·16
5	73°	2·9	24·58	7	60°	2·8	23·88
7	73°	2·7	25·24				
1	70°	5·0	22·62	1	50°	9·1	23·68
3	70°	3·6	23·77	4	50°	4·1	23·28
5	70°	3·0	23·90	7	50°	3·0	23·70
7	70°	2·7	24·69				

during 58 per cent. of the stroke; this was observed at each position of the reversing lever of the small cylinder. This result might almost have been expected, taking into consideration the ratio of the volumes of the two cylinders, namely 1 to 2·04. In order therefore to work to the greatest advantage, the distribution of the steam should be so arranged that *the admission into the large cylinder may be constant, no matter what may be the position of the reversing lever of the small cylinder*, and the admission into the large cylinder should depend upon the ratio of the volumes of the two cylinders.

It must be observed however that the variations in the admission into the large cylinder within the limits of 50° and 70° of the reversing screw, corresponding with admissions of from 50 to 67 per cent. of the stroke, have very little effect on the consumption of steam. But on the other hand, if the admission into the large cylinder is less than 50 per cent. of the stroke, the expenditure of steam per horse-power increases perceptibly, and becomes greater as the admission into the

large cylinder is less. This can be gathered from tests made in 1883 with the compound engine in the testing shed, which gave the results shown in Table 19.

TABLE 19. *Compound Locomotive in Testing Shed* 1883.

No. of Test.	Mean Boiler-Pressure above atmosphere. Lbs. per square inch.	Position of Reversing Lever of Small cylinder.	Position of Reversing Screw of Large cylinder. Admission in percentage of stroke.	Nominal Expansion, number of times.	Revolutions per minute.	Indicated Horse-power.	Consumption of Steam per indicated horse-power per hour.	With or Without Steam-Jackets.
No.	Lbs.	Notch.	Per cent.	Times.	Revs.	I. H.P.	Lbs.	
33	135·5	2	40	9	82	68·5	29·32	without
34	129·9	2	40	9	78	59·8	29·63	without
35	**129·5**	**2**	**40**	**9**	**58**	**51·6**	**26·61**	with
36	**81·4**	**5**	**40**	**4**	**88**	**70·1**	**34·04**	with
37	86·1	5	40	4	93	84·4	31·44	without
38	71·6	7	30	3·4	87	59·2	40·52	without
39	**69·6**	**7**	**30**	**3·4**	**79**	**56·0**	**38·32**	with

So low an economy in the working of the engine is explained on examining the diagrams from the small cylinder, particularly those taken when the admission into the large cylinder was small; they are very irregular in outline, owing to too much compression. These irregularities sometimes attain such a degree that the small cylinder is converted into a regular brake, producing negative work. As was to be expected, the results of these tests prove that it is disadvantageous to give the large cylinder a smaller admission than corresponds with the volume of the small cylinder.

(4) Turning to the question of the economy produced by the steam-jackets and by the compound system, the following conclusions are arrived at :—

(*a*) The steam-jackets on the ordinary engine, while working in the testing shed in the first and second notches, undoubtedly gave a mean economy in steam consumption of 16 to 12 per cent. (see page 315). In the experimental trains the jackets did not generally give satisfactory results, except when the ordinary engine was working in the first notch (page 343); but this must be attributed partly to the loss of steam in warming up the walls of the jackets each time the regulator was opened, and above all to the imperfect draining of the jackets (page 344), whereby they were probably converted into condensers. A better means of draining the steam-jackets must therefore be sought for.

(*b*) The compound system undoubtedly gave an economy of steam and of fuel; the amount of this economy varies perceptibly with the conditions under which the engine is working, and in ordinary work it may be taken at from 15 to 20 per cent.

The greater quantity of water evaporated per pound of wood in the tests with the compound locomotive cannot yet be attributed with certainty to the compound system: it may have resulted from individual peculiarities of the boiler and of the fireman, and also from lack of sufficient accuracy in estimating the consumption of wood. Nevertheless, inasmuch as the compound locomotive consumes less fuel for doing the same amount of work, it will consequently require less blast, and will less frequently need an injurious contraction of the blast-nozzle; whence it is possible to utilise the fuel better in the boiler of the compound engine.

Furthermore, the smaller consumption of steam in the compound locomotive allows of its taking heavier trains wherever there is already a surplus of tractive power as well as of adhesion. This is one of the important advantages of the compound system, which must not be lost sight of when judging of its value.

(5) Considering that the compound locomotive with which the experiments were carried out involves scarcely any complication, and that it costs about the same to build as the ordinary engines, and that a decrease in consumption of fuel lessens the cost of boiler

repairs and of providing feed-water &c., it may be concluded that there is an undoubted advantage in building locomotives on the compound system.

In concluding this paper the author wishes once more to draw attention to the advantages of a testing shop, properly fitted up, for investigating all the conditions of the work done by locomotives and their boilers. An idea can be formed on this subject by comparing the methods described in Parts I and II of this paper, and by noticing that the methods of observation in the testing shop are simple and accurate, and present facilities for calculation and verification; while the others are difficult, minute, very complicated, incapable of verification, and dependent upon all sorts of eventualities that may happen while the train is running. That the author was obliged to have recourse to such complicated and difficult processes, whereby this work was extended over several years, was because of the primitive nature of his testing shed, and chiefly because he had no brake-dynamometer such as would have rendered it possible to carry out the tests under all desired conditions of pressure, expansion, speed, &c.

(*For Discussion see page* 363.)

ON THE WORKING OF COMPOUND LOCOMOTIVES IN INDIA.

By Mr. CHARLES SANDIFORD,
Locomotive and Carriage Superintendent,
North Western Railway, Lahore.

At the present time, when the question of Compound Locomotives is occupying so largely the attention of railway engineers, any record of practical experience should be interesting. The author has therefore much pleasure in presenting the following particulars and results of the trial which in the early part of 1883 he determined to make on the Scinde Punjaub and Delhi Railway, for testing the value of the compound principle when applied to locomotive engines working under the conditions met with on that line. These conditions are altogether so different from those under which the principle has been tried on the Continent by M. Mallet and in England by Mr. Webb, that its success on the Indian railway appeared sufficiently doubtful to render this independent experiment desirable.

In order to carry out the trial at a moderate cost, and in such a manner that in the absence of success it should be easy to revert to the ordinary plan, two engines were selected,—the "Vampire" and the "Vulcan,"—which had come into the shops for heavy repairs, both of them requiring new cylinders. Each had 3 ft. 6 ins. leading wheels, and four 5 ft. wheels coupled. The Vampire had 15-inch cylinders with 22 inches stroke, and the Vulcan 16-inch cylinders with 24 inches stroke. As the alterations were confined almost wholly to the cylinders and valve-gear, the accompanying drawings, Plates 80 to 86, not only show the engines as they now run compound, but also give their principal dimensions in their original form before being compounded. The drawings and patterns for the requisite alterations were prepared in 1883; but the actual conversion was not made and the engines tried in steam until June 1884.

In the Vampire, Plates 80 to 82, the two original 15-inch cylinders were replaced by an 18-inch high-pressure and a 24-inch low-pressure cylinder, these being as large as could conveniently be got in, as shown in the plan and cross section, Plates 81 and 82; the original stroke of 22 inches was retained in each cylinder. The slide-valve of the low-pressure cylinder is worked direct, Plate 80, and that of the high-pressure through the intervention of a rocking shaft R; excepting the slight modification thus rendered necessary, the gear remains precisely the same as it was, the distribution being controlled by a Stephenson link-motion; the arrangement works exceedingly well and gives no trouble. To meet the contingency of the high-pressure cylinder sticking on a dead centre, a cock C is provided, Plates 80 and 82, by which steam can be admitted direct from the boiler into the steam-chest of the low-pressure cylinder. As the result of an extended trial the engine has been found to work satisfactorily, and there has been no difficulty whatever in starting. Being regularly employed on goods and mixed trains, which are timed at 18 to 22 miles per hour, the engine takes with ease a gross load of 500 tons including itself, and consumes $13\frac{1}{2}$ per cent. less fuel than an ordinary coupled engine with 16 ins. × 24 ins. cylinders. The records of performance in running 6555 miles showed an average consumption of 33·10 lbs. of coal per train-mile, with an average gross load of 489 tons, at an average speed of 20 miles per hour. For the ordinary engines on the same run the average consumption was 38·28 lbs. of coal per train-mile, under very similar conditions as to load and speed. The fuel used was Bengal coal, the value of which will be judged from the comparative tests given in the Table appended (pages 360–361).

The other engine, the Vulcan, Plates 83 to 86, as now compounded has four cylinders, as shown in the plan and cross section, Plates 84 and 86, the two original 16-inch cylinders having been replaced by a pair of $11\frac{3}{4}$-inch high-pressure outside cylinders and a pair of 17-inch low-pressure inside cylinders; the original stroke of 24 inches has been retained for all four cylinders, and the crankpin of each high-pressure cylinder is fixed opposite to the crank of the

corresponding low-pressure cylinder, as shown in Plates 83 and 85. Here again the distribution is by a Stephenson link-motion, with the addition of rocking shafts for working the slide-valves of the high-pressure cylinders; and the arrangement is found to work well. The two high-pressure cylinders being of course connected to right-angled cranks, the engine as might be supposed starts freely in any position. It is regularly employed on goods and mixed trains, which are timed at 18 to 22 miles per hour; and hauls gross loads of 500 to 550 tons including itself. It has been fairly tested over an extended period in charge of a driver of ordinary capabilities, with the result that in the first half-year of 1885 he took the highest prize for economy in fuel, and in the last half-year the Vulcan was still at the head of the list, being nearly 13½ per cent. lower in consumption than any of the ordinary engines in the same district. The first records of performance were obtained in running 14,830 miles, in which the consumption averaged 33·13 lbs. of Bengal coal per train-mile, with an average gross load of 520 tons, at an average speed of 20 miles per hour.

The alteration of the four-cylinder engine was more expensive than of the other engine with only two cylinders, inasmuch as the substitution of the four cylinders called for new crankpins and connecting-rods for the outside cylinders, besides the addition of these cylinders themselves. But had the experiment failed, the Vulcan with its two outside cylinders removed, and with a simple alteration of the steam-pipes, could readily have been put to work again as an ordinary engine with 17-inch inside cylinders; whereas in the case of the Vampire with only two cylinders, and these of different diameters, failure would have meant new cylinders. Where compound engines can be built completely new, with every advantage in original design, these considerations may seem less important; but elsewhere their force will be felt, and it will be readily understood why the designs in the present instances took the particular forms here described.

In recent discussions upon the working of locomotives a good deal of stress has been laid on the disadvantage of coupling-rods; and in

the author's opinion much more has been said against them than they deserve. Having found their brasses run for years with scarcely any appreciable wear, he believes that whatever wear there is will be more than counterbalanced by the unequal wear certain to be produced on wheels which can revolve at different speeds, as can the uncoupled wheels of the three-cylinder compound locomotives. In the four-wheel coupled engines, with solid coupling-rod ends and brass bushes forced into the rod ends, the wear is very small; from 3 to 3½ years or from 70,000 to 90,000 miles is a common record, and then the play is inconsiderable, say one-tenth of an inch.

In the four-cylinder compound engine it may be mentioned that the exhaust steam from the high-pressure cylinders was at first led direct into the steam-chest of the low-pressure cylinders through short straight pipes, as shown by the dotted lines at P in Plate 86. Afterwards by way of experiment it was led through longer pipes taken round the smoke-box, as now shown by the full lines in Plate 86, and also in the plan, Fig. 54, Plate 85; and this appears to be a practical improvement by giving drier steam in the low-pressure cylinders, and steadier pressure in the larger capacity of the low-pressure steam-chest. The alteration was made purely to test the effect, and not to remedy any observed shortcoming.

Regarding the blast, the four-cylinder engine has a good deal sharper blast and is capable of steaming better than the two-cylinder; but the latter is never short of steam, although it has only one puff against the other's two. There is no doubt the four-cylinder engine can do more, and uses more steam when pushed, than the two-cylinder. In consumption of oil there is a small difference against the four-cylinder engine, which is only natural.

That the compounding of these two locomotives has been attended with economy in consumption of fuel is unquestionable; and they are decidedly more powerful than the original engines were. At the same time from a driver's point of view they are not more complicated, and do not require any special jockeying; he has no more to do than before, and no special training is necessary; the

same regulator and reversing lever, cylinder cock, &c., are in use; and any driver can step on the foot-plate and take a train without any hitch. Drivers like the two-cylinder engine best, as does the author for moderate loads. If the boiler pressure were higher, both engines would do still better; for the present working limit of 120 lbs. per square inch is scarcely enough to do full justice to the compound system. From a mechanic's point of view of course the four-cylinder engine is more complicated than the original engine from which it was altered, although the same can scarcely be said of the two-cylinder engine. It is also very much simpler to build or to convert on the two-cylinder plan than on the four-cylinder, and within the limits of power possible the author considers the two-cylinder plan preferable; but the limit of power is sooner reached, and the four cylinders have the advantage of allowing greater power to be secured. In the four-cylinder engine rather heavy wear was anticipated on the eccentric rings, in consequence of their having to work four valves instead of two; but this result has not been experienced. In the original crank-axles of either engine, as shown in the drawings, no weakness has been perceived as a consequence of the increased power from compounding. Although the original gear and axles, which have been retained in compounding, are unquestionably lighter than would be designed for the present larger cylinders, still they have thus far stood the test of daily working, and go to prove how large a factor of safety is usually provided. If it seem unwise to submit these altered engines to criticism, it may be urged as the plea for doing so that the end has been found to justify the means.

The line over which these engines work is practically level, but is exposed to strong side winds. The stoppages are numerous, the runs averaging less than 6½ miles. Fuel being exceedingly expensive, as seen in the Table appended (pages 360–1), economy is imperative.

In conclusion the author may state that, were it not for conditions certain to arise, which will call for more powerful engines in future than he yet sees his way to designing on the compound principle, he would have no hesitation in accepting the responsibility of recommending it; and where its adoption can be carried out with

(*see continuation on opposite page*)

Comparative Trials of Fuel in daily train service with ordinary locomotives (not compound).

No. of Trial.		Trial I.		
Description of Fuel.		Crown Patent Fuel.	Ebbw Vale Coal.	Bengal Coal.
Average No. of Vehicles per trip	No.	27·11	27·85	26·42
Mileage of Trials.	No. of trips	154	174	43
	Miles per trip	108	108	108
	Total miles	16,632	18,792	4,644
Gross Weight of all Trains, including engine and tender loaded		Tons. 39,385	Tons. 45,202	Tons. 9,852
Consumption of Fuel.		Lbs.	Lbs.	Lbs.
	Total lbs.	441,467	563,745	144,084
	Per mile, lbs.	26·54	29·99	31·02
	Per mile per vehicle, lb.	0·98	1·07	1·17
Cost of Fuel. *Rupees, annas, pies*		*R. a. p.*	*R. a. p.*	*R. a. p.*
Cost per ton at Karachi (K), and at Ghaziabad (G); the latter is a junction 13 miles east of Delhi, and 337 from Lahore		K 16 6 0	K 15 10 3	G 16 15 0
Freight per ton to Lahore from Karachi and from Ghaziabad		K 11 10 3	K 11 10 3	G 4 13 3
Total cost per ton at Lahore *R. a. p.*		28 0 3	27 4 6	21 12 3
Do. do.	*£ s. d.*	£2 16 0½	£2 14 6¾	£2 3 6½
Cost at Lahore per vehicle per mile	anna	0·20	0·21	0·19
	penny	0·300	0·315	0·285

Trial I was carried out during 1885 on the run of 108 miles between Lahore and Phillour; the average speed was 25 miles per hour.

The freight per mile for the fuel to Lahore is 0·1 pie per maund (82·286 lbs.) = 0·34 penny per ton.

8 pies = 1 penny; 12 pies = 1 anna = 1½ penny.

8 annas = 1 shilling; 16 annas = 1 rupee = 2 shillings.

(*continued from opposite page*)

Comparative Trials of Fuel in daily train service with ordinary locomotives (not compound).

Trial II.			Trial III.	
Crown Patent Fuel.	Ebbw Vale Coal.	Bengal Coal.	Bengal Coal.	Wood.
27·77	28·49	25·11	30·47	31·53
209⅓	143¼	657¾	1635	5284
108	108	108	103	103
22,605	15,470	71,033	168,411	544,295
Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
644,090	517,092	2,483,992	7,105,756	44,030,064
28·49	33·42	34·97	42·25	80·89
1·02	1·17	1·39	1·39	2·56
R. a. p.	*R. a. p.*	*R. a. p.*	*R. a. p.*	*R. a. p.*
K 16 6 0	K 15 10 3	G 16 15 0	G 16 15 0	
K 11 10 3	K 11 10 3	G 4 13 3	G 4 13 3	
28 0 3	27 4 6	21 12 3	21 12 3	8 0 7
£2 16 0½	£2 14 6¾	£2 3 6½	£2 3 6½	£0 16 1
0·20	0·23	0·22		
0·300	0·345	0·330		

Trial II was carried out under very similar conditions to those of trial I.

Trial III was conducted with slightly different load. The results with Bengal Coal are from a three months' trial in 1883. The results with Wood are from twelve months' trial, extending over three months in each of the four years 1881-82-83-84. The cost of wood at Lahore is 29 *r.* 8 *a.* 6 *p.* per 100 maunds = 16*s.* 1*d.* per ton.

advantage in other respects, there can be no doubt it will also pay in regard to economy of fuel. For working a grade of 1 in 26 he is now employing engines with 18 × 26 inch cylinders and six coupled wheels of 4 ft. 2 ins. diameter, putting three engines on the same train of 250 tons exclusive of the engines; one engine pulls in front and two push behind, being so placed for the sake of brake power. It is therefore not easy to design a compound engine as powerful as is here necessary; nothing less than 20,000 lbs. of tractive force at 7 miles per hour would at all approach the requirements.

Discussion.

Mr. Borodin said the conclusion at which he had arrived in regard to the uneconomical results of working with too high expansion and too large cylinders was certainly not a new one; it had previously been stated by Mr. D. K. Clark in his book on "Railway Machinery," where at page 85 he said: "The important losses by condensation in outside cylinders, which accompany great expansions, account for the inability to work these engines expansively and economically, with admissions materially less than 30 per cent. of the stroke." This had been the case in his own experiments described in the paper just read. Using outside cylinders, he had found by both methods of testing — in the experimental shed and when running with the experimental trains— that for the ordinary locomotive the most advantageous working was with the reversing lever in the second notch, which gave an admission of 30 per cent. For the compound locomotive this was not the case; on the contrary, as stated in page 350 of the paper, the economy of steam was slightly greater with an admission of only about 15 per cent. In this respect again the results of his own experiments agreed not only with one another, but also with the results obtained by Mr. Clark and with those arrived at by Mr. Delafond at the Creusot Works. The statement on page 343, that the proportionate work done in the small cylinder of the compound engine decreased as the admission into the small cylinder increased, was likewise not a new one; but as it was not always well understood, it was worth drawing attention to it; and the results proved that his own experiments were not far from the truth in this matter.

Mr. Druitt Halpin said Mr. Borodin's paper must have cost the author a great amount of labour; it gave merely the results, but the calculations and tables and the working out of the indicator diagrams must have occupied a very large amount of time. Mr. Borodin had dealt with the subject in a rather different way from Mr. Marié, whose

(Mr. Druitt Halpin.)

paper on the consumption of fuel in locomotives had been read a couple of years ago (Proceedings 1884, page 82). In that paper the consumption of coal and water had been given on the one hand, and on the other the load, gradient, and speed; and from these the conclusions were drawn. In the present paper, on the contrary, reference had not been made in any way to the load; the author had quite confined himself, and properly so, to the consumption of water and coal and to the interpretation of the indicator diagrams.

In regard to the indicator diagrams, he feared that an error had unwittingly been fallen into, which might to a great extent vitiate the otherwise high value of this paper. In Fig. 1, Plate 64, was shown the arrangement adopted for attaching the indicators to the engine, where it would be seen that unfortunately the pipes from the cylinder to the indicators were very long and very much bent, and he did not know whether they were clothed or not; these circumstances had a most serious influence on the indicator diagrams so obtained. In Fig. 61, Plate 88, was shown a diagram taken from an engine constructed by Mr. Windsor in Rouen, in which the dotted line showed that when the engine was first indicated it appeared not to be giving out anything like the power it ought to be giving. This result was discovered to be solely due to the fact that the pipes leading to the indicators were at least as long as they were in Fig. 1; and it must be remembered that the engine indicated in Fig. 61 had the advantage of working inside a warm engine-house, whereas that shown in Fig. 1 was outside. When the indicators were afterwards fixed right on the cylinder, without any intervening length of pipes, the result was at once a net increase of 38 per cent. in the mean pressure in the cylinder, as shown by the full line in Fig. 61, this very large increase in the diagram being due solely to the close proximity of the indicator. To a very great extent a similar accident he feared might have happened in Mr. Borodin's diagrams, in which case it would be necessary to introduce some large and unknown correction in order to get them right.

With regard to the question of steam-jackets, into which Mr. Borodin had also gone very thoroughly, he was afraid that he had laboured under great disadvantages. At the end of the paper

(page 353) the defective draining of the jackets was referred to as having probably transformed them into condensers. Of course they were turned into condensers, for all steam-jackets must be condensers; and the more steam they condensed, the better were they acting. He had himself got the consumption of water through the jackets as high as 17½ per cent. of the total consumption of water by the engine; and had always found that, the greater the condensation in the jackets, the greater was the total economy. When the jacket was recognised as a condenser, the necessity would also be recognised of applying a proper air-pump for clearing it; because if a condenser were erected without an air-pump, it would speedily result in a crisis that was very undesirable. The steam-trap shown in Fig. 7, Plate 67, which was used for draining the jackets, was well known as having been invented in this country and used for very many years; but it was a very deceptive trap. In the discussion at Liége upon Mr. Webb's paper on his compound locomotive (Proceedings 1883, page 457), he had been able to give some particulars of tests made by Mr. Bède with that very trap upon a compound engine, where it was a question of water consumption only, quite independent of coal; and there the result had been that when the trap was not working properly it had augmented by more than 51 per cent. the proper consumption of water by the engine. That had certainly been a very aggravated instance, because the arrangement had there been that the steam circulated first through the jacket of an intermediate receiver and then through that of the smaller cylinder, before entering into the smaller cylinder and passing thence into the larger. There was little good however in pointing out the loss consequent upon the use of the steam-trap shown, unless some way could be proposed for remedying it. In Fig. 59, Plate 87, was accordingly shown an arrangement which would get over the difficulty altogether. It consisted merely in leading a drain pipe P from the bottom of the cylinder jacket J to a small auxiliary injector I, which was introduced for the purpose into the boiler feed-pipe F, a piece of the feed-pipe being cut out for the injector to be introduced there. The feed-water was driven through the feed-pipe F by the ordinary injector N, as usual; and in passing

(Mr. Druitt Halpin.)

through the small auxiliary injector I, the feed-water by lateral mechanical friction simply picked up the whole of the condensed water brought by the drain-pipe P from the jacket, and carried it all right through into the boiler: so that the whole of the water was got back, and also the whole of the heat. A much more elegant way of accomplishing the same object was that invented by Mr. Gresham, which also worked very successfully; it did away with any auxiliary injector, by simply taking the drain pipe from the bottom of the steam-jacket and leading it to the overflow of the ordinary injector; and when once the ordinary injector was started, it would pick up the water out of the jacket through the overflow, and send the heat and the water all back into the boiler without any loss. In this plan, shown in Fig. 60, Plate 87, a valve was added on the overflow of the injector, so that, as soon as ever the injector was started, the valve should shut and the overflow cease; then the injector took up the jacket water through the overflow, and sent the whole through into the boiler. There was also a third means of perfectly draining the jackets, much simpler than either of the above two methods.

The action of the steam-jackets was a very important matter in connection with engines: and though to some extent it might not be understood as it ought to be, it seemed to himself that it depended on three things which were totally distinct from one another. The first was expansion. Of course steam-jackets would be of no use whatever unless there were expansion, which meant difference of temperature during the stroke; and naturally, the greater the expansion, the greater was the difference of temperature, and the greater was also the efficiency of the jacket. But the two other elements also influenced the efficiency of the jacket very strongly. The second was piston-speed. Transmission of heat was largely a question of time; and naturally the lower the piston-speed at which a jacketed engine worked, the greater was the economy attending the jacket; whilst for high piston-speed the cylinders were often not jacketed. The third very important element affecting the value of jackets was the ratio of the jacketed surface to the volume of the cylinder. A clear idea of the importance of this ratio was readily

obtained by contrasting the multitubular locomotive boiler, which presented the maximum of heating surface for the minimum of volume, with the plain cylindrical blast-furnace boiler, which had the minimum of heating surface for the maximum of volume; such a contrast exhibited the utmost difference in the ratio which the volume of water to be heated in the boiler bore to the area of the heating surface. How very widely the ratio of area to volume varied in the case of steam-jackets was exemplified by the accompanying Table, in which the cylinders were throughout assumed

Ratio of Jacket Surface to Cylinder Volume.

Size of Cylinder.			Area of Jacket Surface.			Area of Jacket Surface per cub. ft. of cyl. vol.		
Diam. Feet.	Stroke. Feet.	Volume. Cub. Ft.	Barrel alone. Sq. Feet.	Barrel with Two ends. Sq. Feet.	Barrel with Four ends. Sq. Feet.	Barrel alone. Sq. Ft.	Barrel with Two ends. Sq. Ft.	Barrel with Four ends. Sq. Ft.
½	½	0·098	0·78	1·17	1·57	8·00	12·00	16 00
1	1	0·785	3·14	4·71	6·28	4·00	6·00	8·00
1½	1½	2·65	7·07	10·60	14·14	2·67	4·00	5·33
2	2	6·28	12·57	18·85	25·13	2·00	3·00	4·00
2½	2½	12·27	19·63	29·45	39·27	1·60	2·40	3·20
4	4	50·24	50·27	75·40	100·53	1·00	1·50	2·00
5	5	98·17	78·54	117·81	157·08	0·80	1·20	1·60
7½	7½	331·46	176·71	265·07	353·43	0·53	0·80	1·07
10	10	785·40	314·16	471·24	628·32	0·40	0·60	0·80

to be of equal diameter and stroke, the dimensions being taken in feet. The ratios here given were also represented graphically by the three curves drawn in Fig. 62, Plate 88. The table and curves showed the ratios of jacket surface to cylinder volume when the barrel alone was jacketed, when the cylinder ends were also jacketed, and when still further the two ends of the piston were also kept

(Mr. Druitt Halpin.)

heated by a supply of steam into the interior of the piston body through the piston-rod. It was here seen how very great a difference was produced in these ratios by increasing the size of cylinder, and how desirable therefore it was, as far as one function of the efficiency of the jacketing was concerned, to divide the work among cylinders of smaller size, rather than to perform the whole in one cylinder of larger size. In his opinion it was a popular error to suppose * that the maximum amount of jacketing-surface possible on a cylinder was the barrel together with the two ends; in reality a good deal more could be got. The question of the flow of heat through the walls of the cylinder was somewhat analogous to that of the flow of water. Through a plain parallel hole in the bottom of a tank a certain quantity of water would flow; but if the hole were made of the vena contracta form a much greater flow would be obtained without increasing the original minimum diameter. Exactly the same thing could be done by a little modification in the construction of the steam-jacket. Most jackets were made with plain barrels, for convenience and economy of construction. But by covering the whole outside of the cylinder barrel with ribs, as shown in Fig. 63, Plate 88, a greater amount of heat could be got through into the inside of the cylinder than through a plain barrel without ribs; and in this way the difficulty of promoting the flow of a greater quantity of heat through the cylinder walls could be got over. The external ribs presented a large surface for the heat to go into the cylinder barrel, through which it could then easily pass and come out into the inside of the cylinder, because the inner surface of the cylinder was always kept clean by the working of the engine; and this inner surface was covered by any deposition of moisture which took place owing to internal condensation, while the outer surface with its projecting ribs took up heat from the steam in the jacket.

It was mentioned in page 298 that the engine in the testing shop had to be worked with high grades of expansion and comparatively low pressures in order to develop not more than about 90 horse-power, because the author had not got a proper brake for absorbing the

* See Proceedings Institution of Civil Engineers 1881, vol. lxvi, page 143.

whole power. It was certainly a great misfortune in such valuable experiments not to have had one, because without such a brake the engine was being tested under such totally different conditions from ordinary running that a comparison could hardly be fair. In pages 338-9 the compound engine in running on the road was stated to have developed approximately from 220 to 240 H.P.; whilst in the laboratory experiments the maximum limit of 90 H.P. was attended with the great inconvenience of having to do supplementary driving with another engine, by which the tools in the workshop were partly driven. Brakes could be put up very cheaply, for much less than had been spent upon the whole of the driving connections and counter shafting and brackets shown in Plates 64 to 66. In Figs. 56 and 57, Plate 87, was shown a brake that could be put on in an hour at any time when an engine came in for a couple of hours, and could be run up to 400 or 500 H.P. The great trouble in brakes hitherto had been the way they had to be worked. The friction brake was one of the purest modes of converting mechanical power into heat; and any one who had seen an engine tested in that way, as at the Royal Agricultural shows, would know what a trouble it was to have to attend to a brake which had to be worked like the steering wheel of a ship, always up and down; so much so indeed that, if the rapidly changing variations in speed were recorded with a Mosorop recorder or other instrument of that sort, he thought engineers would be deterred from undertaking to manage it. The chief cause of all the trouble was that the only medium whereby the whole heat developed on the brake was taken up was the surrounding air, which was by far the worst medium known for taking up heat; but if the air were simply replaced by water as the heat-absorbing medium, the whole process was very much simplified. Such an arrangement was shown in Figs. 56 and 57, Plate 87, which represented an ordinary Appold friction-brake, with simply the addition of an arrangement for keeping it cool in working. For this purpose cold water was delivered by the pipe C to the inner face of the rim of the brake-wheel; and as soon as it became heated by contact with the hot rim its volume increased, it lost centrifugal force, and drew back from the rim, leaving its place

(Mr. Druitt Halpin.)

to be supplied by fresh cold water. The discharge pipe H had its mouth spread out, and acted like one of the cream-skimmers in the centrifugal cream-machines, skimming off continuously the innermost layer of hottest water; it was provided with a cock for regulating the rate of discharge. In that way absolute control was practically maintained over the working of the brake. With one of these brakes, put up last year by Professor Thurston, 500 horse-power had been absorbed without the slightest trouble; the wheel was 5 feet diameter and 2 feet wide, and was running at 100 revolutions per minute at the time of absorbing that amount of power. The engine on which Mr. Borodin's tests had been made had the very convenient gauge of 5 feet 3 inches, giving 2 feet 9 inches clear width between the eccentrics; and there was 1 foot 7 inches height from the centre of the driving axle to the bottom of the boiler. If therefore a split pulley of $2\frac{1}{2}$ feet diameter and 2 feet width were simply placed on the driving axle, it could take up from 250 to 300 H.P. with the greatest ease; such a brake could be put on in half an hour, and in that way an engine could be tested in a very short time. Wherever, owing to the gauge being narrower or to the use of inside cylinders, it would be impossible to put a split dynamometer pulley upon the driving axle as proposed, one or two dynamometers could always be used, having their axis in line with the driving axle, and driven by drag links taking hold of the side-rod crank-pins. The Royal Agricultural Society he believed were going to run brakes again at Newcastle next year, and if so he hoped they would run with the cooled brake and would let each engine have its own brake, because the difference in friction with these brakes would make a vast difference in the running of the engines. The mode of testing in the Royal Agricultural Society's former trials had always been attended with the additional disadvantage of working through a universal coupling, which involved a further unknown amount of friction.

On page 331 of the paper were given some extraordinary figures in regard to the initial steam pressure in the cylinders, which in some of the experiments was stated to have gone down to as low as only 53 per cent. of the boiler pressure. In such cases there must have

been something radically wrong, for it was hardly worth while to make boiler steam of 100 lbs. pressure if only 53 lbs. initial pressure were to be got in the cylinders; and the question was, how did the loss arise. There was practically little or no radiation, because of the steam pipes passing through the boiler; the reduction could therefore be due only to constricted passages and to friction. Although there must necessarily be some drop in pressure from the boiler to the cylinders, yet if the pipes and passages were made large enough the loss of pressure would thereby be proportionately diminished. The only objections to larger steam pipes were two: radiation and expense. In locomotives with the steam pipe inside the boiler there was no loss by radiation; and the increase of price for larger pipes was a very small matter. In Mr. Stroudley's recent paper upon the locomotives on the Brighton line* this very subject of the decrease of pressure had been touched upon; but the results there given were not concordant. With the same boiler-pressure, the same piston-speed, and the same degree of expansion, there was stated to have been in one case no drop at all, and in another case a drop of 10 lbs.; and it was not explained in any way how these discrepancies arose. In his own opinion they were simply due to the one broad fact that all steam velocities in the steam pipes of locomotives were allowed to be too high. In some of the experiments described in Mr. Stroudley's paper he found the steam velocity must actually have come up to 420 feet per second, and in others to 394 feet, and so on. He had never yet seen any indicator diagram free from a noticeable drop of pressure where the steam velocity through the pipe exceeded 66 feet per second; and in order to get so low a velocity, a pipe was required of double the diameter or four times the area, to do the work properly.

Mr. Henry Davey considered one of the most interesting points in Mr. Borodin's paper was the question of the advantage of the steam-jacket. Having listened to discussions upon the steam-jacket

* See Proceedings Institution of Civil Engineers 1885, vol. lxxxi, Table vii, facing page 108.

(Mr. Henry Davey.)

for the last fifteen years he had never yet heard of any set of experiments thoroughly carried out for deciding that point. It was very evident from the statements made in the present paper that the value to be assigned to the steam-jackets which had been used in Mr. Borodin's experiments was somewhat uncertain. It was acknowledged that the circulation might not have been quite perfect; and he did not gather from the paper whether the ends of the cylinders were jacketed as well as the barrel. In order to make an exhaustive experiment for thoroughly determining the value of the steam-jacket, the cylinder he considered ought to be entirely enveloped in a large volume of steam, by enclosing it bodily within a vessel filled with steam; in that way the value of steam-jacketing would be accurately arrived at.

The majority of published experiments on steam-jackets he had found were much vitiated by the experiments themselves not having been carried out under conditions which would give accurate results. It was highly desirable that a set of experiments should be carried out under proper conditions, so that a reliable formula might be arrived at for expressing the true value of the steam-jacket. The question was one that had many important bearings. In the first place, for the jacket to be of any service at all, it must be a steam-jacket and not a water-jacket. Many years ago he had discontinued the application of steam-jackets to mining engines which were made compound, for the simple reason that in nine cases out of ten he found the jacket was worse than useless. It was very seldom in mines that engines could be placed in such positions that the jackets could drain themselves freely into the boiler; and unless that condition could be fulfilled, the jacket was a great source of danger, instead of being the great advantage to the engine that it should be. In the majority of mining engines that he had fitted with steam-jackets, he had found on visiting the mines some time after the engines had been erected that the drain-pipes were never opened, and the jackets were full of water. As it was much better to have no jackets at all than that they should be so neglected, he had discontinued putting them on mining engines for that simple reason. The best results he had got from jackets had been from Cornish

engines in Cornwall; and there the condition was always carefully observed that the engine should be high above the boiler, and that there should be a large drain-pipe from the jacket back into the boiler, and a very large steam-pipe to supply the jacket with steam at full boiler-pressure, and also that the valves should always be wide open. All these were necessary conditions. In many engines now made with short cylinders of large diameter, the jacket was almost useless, because it was round the barrel only of the cylinder, while the ends were left unjacketed, so that not more than half the actual surface of the cylinder was jacketed; and in very few cases was there provided a proper means of draining. The jacket had another important bearing, namely its relative value on the two cylinders in a compound engine. There was a difference of opinion as to whether more water was precipitated in the high-pressure cylinder or in the low-pressure: as a general rule he thought it would be found that more water was precipitated in the high-pressure cylinder. It was also a prevalent practice to place the steam-jacket on the low-pressure cylinder, in which the expansion was carried to the furthest extent, and not to jacket the high-pressure cylinder at all. That was a practice which he believed to be altogether wrong; the value of a jacket he considered was greater on a high-pressure than on a low-pressure cylinder in the majority of cases. All these however were points upon which reliable data were still required from carefully conducted experiments.

M. Anatole Mallet of Paris, who was invited to attend the meeting, regretted that he was unable to do so; and sent the following remarks in reference to Mr. Sandiford's paper:—

"More than ten years' experience in the construction of compound locomotives has confirmed me in the opinion that, wherever not tied by the diameter to be given to the large cylinder, the use of only two cylinders—a larger and a smaller—is to be preferred, and meets all requirements. The large cylinder can generally be got as much as 26 inches in diameter, which with 18 inches diameter for the small cylinder is sufficient for the most powerful locomotives with four

(M. Anatole Mallet.)

and six coupled wheels. (See Proceedings 1879, page 343 and Plate 40.)

"It is better that the ratio of the capacity of the larger cylinder to that of the smaller should be not less than two to one; and it is indispensable that the reversing gear should be so arranged as to allow of varying the cut-off in each cylinder at pleasure, independently of the other. From Mr. Borodin's paper is seen the importance of providing a suitable cut-off for the large cylinder.

"The communication between the two cylinders should always be so arranged that whenever required each may receive boiler steam and exhaust into the chimney, as in ordinary locomotives. Besides ensuring ample power for starting promptly, the independent working of the two cylinders may prove a great advantage in the event of any mishap to either cylinder or to its motion, or of any chance reduction in boiler pressure on the road; moreover the tractive power can by this means be readily augmented at any moment. This arrangement has been adopted in the compound locomotive used in Mr. Borodin's experiments, and is carried out without any appreciable complication either in construction or in working. It has been used by myself from the outset, and experience has more than ever confirmed me in adhering to the plan.

"Wherever the larger of the two cylinders cannot be got large enough—which will scarcely ever occur except in engines with eight coupled wheels—it is decidedly best to have recourse to four cylinders, two high-pressure and two low. My own plan is to arrange them in pairs, the high-pressure pair working on a set of four or six coupled wheels, and the low-pressure pair on another similar set. The wheels driven by the high-pressure cylinders are fixed under the hind end of the engine, while the low-pressure cylinders drive the wheels of a truck or bogey carrying the front end. Despite its long wheel-base, the engine can thus run round sharp curves easily. The gear is throughout exactly alike for each of the four cylinders. The steam-pipes from the boiler to the high-pressure cylinders are fixed like those of ordinary locomotives; and the communication from the high-pressure to the low-pressure cylinders is through a single jointed pipe; the swivel joint is all

the easier to keep steam-tight because the steam inside the pipe is already expanded down to 50 or 60 lbs. per square inch. For light roads this plan presents the advantage of distributing the load over a long wheel-base, without involving difficulty in running round curves. It also allows of building compound engines powerful enough to meet all possible needs, and thus to fulfil the requirements foreseen by Mr. Sandiford.

"On the same principle I have also designed a high-speed express engine with triple expansion in four cylinders; the first, receiving boiler steam of 170 or 180 lbs. pressure, is 18 inches diameter, and the three others are each 26 inches diameter, all four having the same stroke of 26 inches. The 18-inch high-pressure cylinder exhausts into one of the 26-inch as an intermediate cylinder; and this in turn exhausts into the two other 26-inch cylinders, which together act as low-pressure cylinders and exhaust into the chimney. The engine has eight wheels, six of 7 feet diameter, and two of 4 feet. The high-pressure and intermediate cylinder, one on each side, work four coupled wheels; while the two low-pressure cylinders, one on each side, work the two remaining large wheels. The wheel loads are so distributed as to render the adhesion of the driving wheels proportional to the power exerted by the two sets of cylinders. The four coupled wheels are fixed under the hind end of the engine; while the two front drivers with the two carrying wheels and the two low-pressure cylinders are on a swivelling truck or bogey under the front end. This plan admits of a very large boiler, and of distributing its weight equally over all the wheels. As in the preceding case, there is only a single swivel joint in the steam-pipe from the intermediate to the low-pressure cylinders, and the pressure inside the pipe is already reduced by expansion. In this way a very powerful engine could be obtained, with flexible wheel-base, economical in working, and weighing 55 or even 60 tons in running order."

Professor Alexander B. W. Kennedy considered that perhaps the most valuable kind of paper which could be presented to the Institution was a record of accurate work done, and so recorded that

(Professor Kennedy.)

all readers might be able to estimate its value for themselves, and even to work out from it their own conclusions. To a very great extent Mr. Borodin's paper came under that description; and certainly it was one which from every point of view the Institution might cordially welcome. It had perhaps a double aspect. It might either be looked upon simply as a record of experiments in relation to certain important points connected with steam-engine economy; or it might be regarded as a record of trials of two different systems of locomotive working, varying more or less from those in general use. Not having himself the good fortune to be a locomotive engineer, he would confine himself to speaking of the paper from the first point of view. He wished to ask Mr. Borodin three questions, the answers to which would perhaps add to the completeness of the paper. First of all, was it to be understood that the discharge of condensed water from the steam-jackets was not regulated by hand, but always took place automatically through the trap shown in Fig. 7, Plate 67? Secondly, were the cylinders in any way covered? the drawing did not show this. And thirdly, was the water from the overflow at D from the upper tank T, Fig. 2, Plate 64, all measured separately? he presumed that was the case, but it was not mentioned in the paper. It would also be interesting to know how the feed-water was measured in the train trials.

As to the results themselves, one remark had already been made by Mr. Halpin which had occurred also to himself, namely that he feared the arrangement of the indicator pipes must have seriously affected the indicator diagrams; in fact he felt sure that it had affected them sufficiently to throw a rather serious doubt on the absolute, though perhaps not so much on the comparative, value of all calculations made from the indicator-diagram pressures. Indeed he was not sorry to have an opportunity of recording his opinion very emphatically that, at the very best, calculations based upon indicator-diagram pressures must be very cautiously accepted, and regarded as only approximate; for without special care as to the position of the indicators, as to the arrangement of the pipes and of the indicator gear, and as to the verification of the springs of the indicators themselves—all of which points were only too often dealt with hap-

hazard—such calculations had neither scientific nor technical value. In a little experimental compound engine, on which he had four indicators, three of them as close to the cylinders as they could go and the fourth with a perfectly straight $\frac{3}{8}$-inch pipe no more than 6 inches long, he had reason to believe that even that short length of pipe absolutely affected the diagrams taken from that indicator; and he had had to alter it with some trouble, in order to get rid of the objection. When Mr. Borodin put the indicators close to the cylinders, he had little doubt that he would find a gratifying increase of indicated horse-power, which would make his engines look better economically than they did at present.

With regard to the calculations of heat, it was assumed in page 304 of Mr. Borodin's paper that practically all the steam condensed in the jackets had been condensed by giving up its heat to the steam inside the cylinders. In his own experiments he was sorry to say that this was not even approximately true. If the trap discharge from the steam-jackets were to be measured while the engines were stopped and standing hot, it would probably be found, provided the traps acted properly, that it amounted to a disagreeably large percentage of the whole discharge when the jacket was fulfilling its proper function whilst the engine was running: at least he was sorry to say that this had been his own experience. In any complete theory of the action of a jacketed engine, it was necessary to take this practical point into account; and also not to lose sight of one theoretical point, which if he did not mistake had been overlooked in a good many valuable engine trials made by the Alsatian engineers:—namely that the heat received by each pound of jacket steam was not the same as the heat received by each pound of steam which went into the cylinder. The jacket steam was virtually formed under condition of constant volume, being condensed without doing work; the cylinder steam was formed under condition of constant pressure. Thus only the cylinder steam received in formation the quantity of heat required for external work. The remarks made by Mr. Borodin in pages 343–4, as to the difference in the efficiency of jackets under different conditions of cut-off, might very well be carefully noted. In reference to the remarks on page

(Professor Kennedy.)

322, about some of the experiments that did not succeed with the jackets working, he thought it might be said once for all that a jacket which was not properly drained by some automatic arrangement was not only useless but a source of great waste. This point was sometimes forgotten, and it seemed to be thought that nothing more was required than to provide that annular space round the cylinder which was called a steam-jacket, and to put some connecting steam-pipes to it. Certainly unless some means were also provided for draining the space automatically, it would be much better to put a blank flange in the steam-pipe to the jacket so as to keep the steam out, for the undrained jacket could only lead to waste. He was glad that the necessity of draining jackets had been put in so emphatic a way by Mr. Halpin, with whom he entirely agreed; and he was much interested in Mr. Halpin's injector proposal, which was quite new to him and extremely ingenious. He had himself used some steam-traps, which he was happy to say he had found to work; but no doubt it was easier to get steam-traps to work continuously in a laboratory than it was under other circumstances.

In the friction brake described by Mr. Halpin the mode of getting rid of the heated water was most ingenious, and he should be greatly interested in seeing it at work. As the question of friction brakes had been raised, he should like to mention that he believed there was a distinct error in the use of an Appold lever arranged in the fashion shown in Mr. Halpin's brake, Fig. 56, Plate 87; and the arrangement which he had himself adopted for obviating the error was shown in Fig. 58, Plate 87, representing a continuous brake of the ordinary kind. The main weight on the brake was at W, the wheel rotated in the direction of the arrow, and the pendulum lever or regulating lever L worked as usual between two fixed stops. What he had done was to hang a little weight A on the outer end of the lever, because he had found that when the engine was running it was always necessary to have some small weight there. This weight and the lever L merely formed an unbalanced part of the brake frame, and acted against the main weight W, so that the magnitude of their moment had to be taken into account as negative in calculating the work done by the brake. If the pendulum lever

were not weighted in that fashion, but its inner end were prolonged backwards and made to pass through some kind of sleeve or to rest against a pin, then the pressure which he thus measured and allowed for would of course be pressure against the side of that sleeve or pin, and would not be allowed for. This he believed might cause a very measurable error of $\frac{2}{3}$ per cent. in the total brake power: an error which was quite worth while taking into account when making accurate measurements. The Royal Agricultural Society he hoped would look into this matter before they made further trials, and, if he was right, would make the necessary alteration.

Mr. Borodin should, he considered, be thanked for the very frank way in which he had stated his results, failures as well as successes. It added greatly to the confidence felt in such results when they were candidly recorded, without any endeavour to make them uphold some favourite view. He hoped Mr. Borodin would be able to continue his experiments with more perfect apparatus, and that on a future occasion he would increase their indebtedness to him by giving further results in the form of another paper.

Mr. W. E. Rich was much interested in the subject of steam-jacketing locomotives, which had been dealt with so elaborately and carefully by Mr. Borodin. The steam-jacketing of the cylinders of compound locomotives had been advocated by himself at Liége in the discussion upon Mr. Webb's paper (Proceedings 1883, page 449). The great exposure of the cylinders in a locomotive rushing along at high speeds must, he thought, be productive of considerable loss; and at the same time it was the universal experience that in compound engines, and especially in those with a moderate piston-speed, a high economy could not be obtained without steam-jackets. It was a pertinent fact that no engine at the Cardiff trials of portable engines by the Royal Agricultural Society in 1872 had the slightest chance of success, if it was not furnished with steam-jackets. Over 30 lbs. weight of steam per indicated horse-power per hour had been consumed in those trials by every engine that had not a steam-jacket. The highest economy obtained by any engine at Cardiff was by the Reading Iron Works engine, which took only 24·14 lbs.

(Mr. W. E. Rich.)

weight of steam per indicated horse-power per hour.* The extra dead weight which would be involved in jacketing the cylinders of locomotive engines might easily be saved in the weight of the boiler, he considered, in consequence of the greater economy of steam that would be produced by using the jackets. With regard to the draining of the jackets, there was no doubt that, as pointed out by Professor Kennedy, a steam-jacket was worse than useless unless it was properly drained. It was very unfortunate that these experiments of Mr. Borodin's had narrowly missed being the most valuable on record, as already remarked by Mr. Halpin and Professor Kennedy, in consequence of a trifling neglect in a few such matters as the length of the indicator pipes, and also owing to the lack of a proper brake on the driving wheel. Having had frequent experience of the errors resulting from long indicator pipes, he was of opinion that even as much as 20 per cent. error was possible in the diagrams taken by indicators having such long pipes as were shown in Fig. 1, Plate 64. Of course if the diagrams were too small, as they would be in such a case, it would follow that the consumption of steam per actual horse-power would be really less than that recorded in the paper.

In applying the compound principle to traction engines and locomotives, it was sometimes urged that a certain amount of pressure must be preserved in the exhaust, in order to produce the requisite draught in the fire. But the day was not far distant, he thought, when it would be found desirable in compound locomotives, and even in compound traction engines, to use a small fan for blowing the fire; for no doubt a boiler could be worked more economically with a fan than with an intermittent blast from the blast-pipe; and an extra effective indicated steam-pressure might be got at the bottom of the low-pressure cylinder diagram by saving all the pressure for the cylinders, and blowing the fire with a small fan-engine which would take very little steam indeed. Smaller tubes could then be used in the boiler, and a larger heating surface could thereby be

* Journal of the Royal Agricultural Society of England, vol. ix, part I, column 44 of Table facing page 61.

obtained in a given space. In all these questions it must be borne in mind that even a small percentage of undoubted economy in the use of steam and fuel meant a great saving in other ways; because, if only 10 per cent. could be saved in the weight of steam used at a given steam pressure, then not only could that 10 per cent. be saved in the weight of the boiler and furnace, but at least 10 per cent. more could be added to the water and coal carried, and this would give more than 20 per cent. gain in extra distance travelled with the augmented load of water and coal, supplying the more economical engines.

On the question of equalising the work in the two cylinders of a compound engine, he believed it was generally recognised that it was impossible with a single slide-valve on the low-pressure cylinder to keep the work equal in the two cylinders with varying degrees of expansion. In order to get equal work in both cylinders, double slides or valves of a special character must be put on both cylinders, and must be separately adjustable.

M. Armand Stévart said that in Belgium no attempt had as yet been made to employ the compound system in locomotives; Belgian engineers had confined themselves to observing attentively what was being done in England. The question depended entirely on the results of actual experiments, which it was necessary to investigate very closely; and he believed it was still necessary to have a greater number of facts that could be relied upon, before coming to a definite conclusion with reference to them. On the one hand, there were advocates of the compound system for locomotives who announced favourable results. On the other hand, there were the careful experiments of M. Marié (Proceedings 1884, page 82), who had obtained the highest economy without the employment of the compound system. No doubt the results obtained elsewhere, and especially in England, by the compound system, appeared to demonstrate that a real economy had been secured; but he thought the facts were at present too few for enabling a satisfactory conclusion to be arrived at.

Mr. F. G. BROOK-FOX said the subject of compounding locomotives had a very great interest for India, especially in the economy of fuel. Not only were large sums paid by the Indian government every year for fuel, the greater portion of which came from England, but large sums were also paid for the carriage of that fuel to a place like Lahore where it was used; every little economy therefore would cause an increase in the dividends. On the North Western Railway—lately the Scinde Punjaub and Delhi—dealt with in Mr. Sandiford's paper, the dividend of 5 per cent. guaranteed by the government had never been paid by the line itself; and one of the causes had been the very high price that had to be paid for fuel. The East Indian Railway, which met the North Western at Ghaziabad, had its own coal-fields at Raniganj, and consequently could charge almost any price it liked for supplying its fuel to other lines. Of course the North Western Railway had its opening to Karachi; and therefore, since the Indus Valley Railway had been opened, English fuel could now be run up from Karachi to Lahore, and thereby a pressure could be put on the East Indian Railway to reduce its charges. But even then, unless the petroleum springs discovered in Beloochistan should be found to yield a large supply, the cost of fuel must necessarily remain very high. The original company having now been superseded, through the line having been taken over by the government, any deficiency of dividend would have to be met from the other Indian railways; but it was none the less necessary that every little economy should be enforced; and any measure which would result in that economy, such as the compounding now carried out by Mr. Sandiford, must be very beneficial to his own line and to other railways situated like it.

Professor RYAN wished to express his own concurrence in the view which had been spoken of by Mr. Halpin as a popular error, namely that when a cylinder was completely surrounded with steam, at its ends as well as its sides, all had been done that was possible in the way of jacketing it. It was true that in the table and curves shown by Mr. Halpin was included also the case of

heating the two ends or faces of the piston by admitting steam into the interior of the piston; this was very good. But in Fig. 63, Plate 88, was shown a section of a ribbed cylinder, by means of which it was represented that it was possible to get more heat through from the jacket into the cylinder than if the cylinder wall were simply made parallel as usual, so as to be of uniform thickness throughout. This view however did not seem to accord with the theory of the conduction of heat. The flow of heat across the thickness of any given substance depended upon the difference of temperature at the two sides that were under consideration, upon the thickness, upon the time, and upon the area exposed. The idea embodied in the diagram of the ribbed cylinder seemed to be that, if the area exposed to heating on the outer side only could be increased in proportion to the volume of the cylinder, some advantage would thereby be gained. But the area to be dealt with in considering the conduction of heat was the area normal to the lines of flow; and it did not follow that, if the area were increased in any other direction, any advantage would thereby be gained. Supposing the temperature of the extreme outside of the cylinder wall to be 310° Fahr., and the mean temperature of the inside to be 300°, there would then be a difference of 10° to cause the flow, or a motive force of that amount to drive the heat through the wall of the cylinder. If the thickness of plate were doubled, the quantity of heat passing through it in any given time would be halved; therefore if the rib were made equal in thickness to the cylinder, there would be only one half the quantity of heat passing through from the top of the rib into the inside of the cylinder at that part. At the same time there were also the side surfaces of the rib to be considered, through which would pass a certain additional amount of heat. The flow from those surfaces would no doubt be in the direction of curves converging inwards; but it was difficult to say what the exact amount of the flow would be. Granting however—what was not nearly correct—that the whole of the rib assumed the temperature of 310°, the result would simply be to get the isothermal line of 310° at identically the same level at which it would have been if the outside of the cylinder

(Professor Ryan.)

had been quite parallel to the inside: so that the value of the rib on the very best terms was only equal to nothing at all. But looking at it strictly, there was no doubt the isothermal line of 310° would follow the outline of the ribs, and that the lower isothermal lines would all be deflected outwards from the cylinder into the ribs; so that there would really be a diminution in the flow of heat into the cylinder at these points.

It should be borne in mind that it was the steam in the jacket which for present purposes was the source of heat, whilst the iron was only the medium by which the heat was conveyed to the inside of the cylinder. Adding these ribs seemed to him like lengthening the direct road between two places in a desert, on the plea that, the more road there was, the better it would be for the traffic. The fact was that, the less the thickness of iron there was to be traversed and the more directly the heat could go through it, the better would be the result; and therefore the thinner the cylinder could be made, the more heat would be got through it in the same time. It might indeed be urged that by ribbing the cylinder it might be made thinner than if its walls were made parallel throughout; but a little consideration would show that nothing would be gained on the whole. Another idea underlying the proposal of a ribbed cylinder appeared to be that the flow of heat from outside to inside did not depend so much upon the conductivity of the iron as upon its capability of receiving the heat from the steam outside and giving it up again to the steam inside the cylinder. Whether the iron got the heat from the steam principally by contact, as he believed, or by radiation, did not make any difference in the present issue. So long as the difference of temperature was maintained, no matter how, the flow would proceed unaltered; and further, increasing the outer surface, while the inner remained the same, would be ineffective. It was true that modern stoves for warming rooms were ribbed in the way here proposed for a steam cylinder; instead of having flat surfaces, there were large ribs of perhaps six inches depth, spreading out round them, and these were found to give largely increased heating power. But in that case the iron was made hot by the fire, and gave up its heat

to the air; which, passing in between the narrow ribs, got heated by contact, and rising, diffused the heat by convection; and as there was continually a fresh supply of air coming in, the extent of the surface giving out the heat to the air did here afford some measure of the efficiency of the apparatus.

The extreme diversity in the results announced during so many years past as having been obtained in experiments on steam-jackets really arose, he believed, from losing sight of the precise kind of engines to which they were applied, and the conditions under which the engines were working. As pointed out by Mr. Rich, there could be no doubt whatever that in the case of slow-working engines with high expansion, such as mill engines, steam-jackets would be useful. The effect produced by the steam-jacket in any particular case depended very much on the rate at which the heat could pass from the steam outside the cylinder to the steam inside. In a quick-working engine with but little expansion and considerable cushioning, a higher mean temperature would prevail inside the cylinder; and the metal of the cylinder would therefore not convey so large an amount of heat from the steam-jacket as in a slow-working engine with large expansion, where the mean temperature inside would be lower, and the gradient of the temperature would therefore be steeper. It was clear that in the latter case there must be a distinct advantage in the use of the steam-jacket; while in so quick-working an engine as a locomotive it was almost equally certain that very little advantage could be derived from steam-jackets. This fact he believed was borne out by Mr. Borodin's experiments; for where his engines had been worked rapidly, the effect of the steam-jackets seemed to have been, if anything, negative. Experiments made in the manner suggested by Mr. Davey, by enveloping the cylinder in a great mass of steam, would theoretically be very interesting; but he was afraid they were hardly likely to have any bearing on practice, because engineers would scarcely make reservoirs of steam to plant their cylinders in. The only thing they could do would be to put the cylinder inside the boiler, as had been done by Trevithick and some of the early engineers; but now that such very high pressures were used, it would be difficult to

(Professor Ryan.)

make the boiler sufficiently strong if its shape were trifled with. On the whole he thought that steam-jackets of the size suggested were not likely to be generally adopted.

In page 338 of Mr. Borodin's paper the compound engine was stated to have given an economy of 22 per cent. in steam and 32 per cent. in fuel, as compared with the non-compound or ordinary engine. To what was this higher economy in the fuel due? It had indeed been remarked by the author in pages 334 and 353 that the higher economy of fuel in the compound engine might have been due to extra careful stoking. In the absence of any positive evidence to the contrary, he thought it must be concluded that it was due either to the stoking or to the furnace, because there did not appear to be any other sufficient reason for this difference between the 32 per cent. gained in the fuel and the 22 per cent. saved of the water. One thing that possibly might affect it was the difference in the blast, because in the compound engine he presumed there would be only half the number of exhausts that there were in the ordinary locomotive, and this might conduce to the more even burning of the fire; or possibly the circumstance of having to produce less steam in a given time might enable more perfect combustion and evaporation to take place. On the whole he thought it must be concluded that the gain in the fuel over the water was due either to more careful stoking or to some superiority in the boiler and furnace of the compound engine.

With regard to the throttling of the steam by the regulator, it had been shown by Mr. Borodin in page 331 that, as the regulator was more and more closed, the initial pressure of the steam in the cylinder fell lower and lower below the boiler pressure. This had been attributed by Mr. Halpin in part to the narrower steam-pipes; but there could be little good in making the steam-pipe larger, so long as the regulator was opened to a much less amount than the area of the steam-pipe; and it followed from Mr. Borodin's remarks in page 331 that the diminution in the initial pressures in the cylinders was due to the closing of the regulator and to that alone.

For the fairness with which good and bad results alike had been given in the paper, he thought Mr. Borodin was much to be

commended. Still in referring on page 322 and elsewhere to certain tests which were not congruous with others, or not in accordance with what would be expected, the actual results of those tests had been omitted. No doubt there had been good reason for that course; but this series of experiments was so valuable that he would not willingly lose any of the records, even though they did not seem to agree well with others. In all experiments indeed he would strongly urge that the whole of the returns should be given in their integrity, however glaringly incongruous they might seem to be, because many advances had been made in scientific discovery simply by the consideration of anomalous and unexpected results.

M. Robert Vinçotte fully concurred in considering that the proper draining of the steam-jackets was a most important matter in steam-jacketing. But the steam-trap shown in Fig. 7, Plate 67, which had been employed for draining the steam-jackets in Mr. Borodin's experiments, appeared to him not to be adapted for effecting any proper draining, inasmuch as it acted upon the principle of expansion in such a way that, instead of discharging the water while it was hot, it did not do so until the water was cold. What was necessary however in a steam-jacket was that the water should be discharged as soon as ever it became water, and therefore while it was still hot. With the steam-trap shown in Fig. 7 he did not believe that the true quantity of heat communicated through the steam-jacket could be ascertained. Having himself had for some years to make experiments on the efficiency of stationary engines, he had always had great difficulty in draining steam-jackets, and had not hitherto seen any device which was reliable in its action; he had found that the steam-jacket was never properly drained, and consequently that the true quantity of heat utilised in it could not be determined. Concerning the method proposed by Mr. Halpin for draining steam-jackets by means of an injector, he should like to have some further explanation. In the arrangement shown in Fig. 59, Plate 87, it appeared to him that the injector would discharge from the jacket not water only, but also steam; it would thereby increase the consumption of steam in the jacket, and would

(M. Robert Vinçotte.)

also diminish the pressure in the jacket, if there was not some sort of valve or trap between the injector and the jacket, to prevent the injector from drawing off steam. If the steam pressure were diminished in the jacket, less heat would be transmitted, and it might even happen that the jacket would act as a condenser.

With regard to the opinion expressed by Dr. Ryan—that in the communication of heat from the jacket to the inside of the cylinder the power of the metal to receive the heat from the hot steam outside did not play a more important part than the conducting power of the metal itself—he was unable to concur in that view, judging from the experience gained in many manufactures, and most of all in that of sugar, as to the practical conductivity of iron and copper for heat. In the sugar manufacture it was a well-known fact that the quantity of heat transmitted through a pipe depended to a great extent on the manner in which the pipe was arranged. If for instance a current of steam was flowing through a pipe that was formed into a coil, it gave out much more heat than if it was only acting upon the outside of a straight tube without running alongside it. The great point was the power of the metal to receive the heat from the steam; and it was the film of water outside that played the greatest part. Whether or not therefore the scheme of the ribbed cylinder would be a good one, he was unable to say; the great point would be whether the film of water in that case remained longer or not upon the surface of the iron.

The fact that in Mr. Borodin's experiments the indicators were not placed close upon the two extremities of the cylinder had been spoken of as having led to a great error in the diagrams obtained. Certainly if the pipe leading to the indicator was very long, the indicator might indicate quite a different state of things from what existed in the cylinder. But on looking attentively at the diagrams exhibited by Mr. Borodin, it would be seen that they did not indicate the kind of errors which were the result of too long indicator pipes. These errors consisted principally in the fact that the indicated pressure lagged a little behind; when the pressure rose, the pencil did not rise quite quickly enough or high enough; and when the

pressure went down, the pencil did not go down quite soon enough or low enough. This would affect the indicator diagram chiefly in the parts representing the beginning of the admission and of the exhaust, where the curve would be a little more rounded. Looking at the diagrams exhibited, he thought they showed clearly that any error, if it existed at all, could not be very great.

Mr. David Greig, having himself made a great many compound high-pressure engines, not locomotives but portable and traction engines, had been greatly struck by the fact that the compound locomotives made in this and other countries had never given such good results as he had himself obtained from the compound engines, which had never given anything below 25 per cent. of gain in the fuel. The much lower gain in the compound locomotives seemed to imply that the circumstances under which they ran must affect their economy; and yet the experiments that he had tried in the yard with the brake were confirmed, in regard to the gain, by the regular working of the compound traction engines, which in his opinion were working under similar circumstances to a locomotive. The variation in the road was what was said to spoil the effect of the compounding in locomotives: whether that was so or not, he was not able to judge; but he should much like to find out, if possible, why such a discrepancy should occur between locomotive practice and the results obtained from compound engines made for other purposes. Of course in a traction engine a considerable advantage was gained by the cylinder being on the top of the boiler, so that all trouble in regard to the draining of the jacket was entirely obviated, inasmuch as the water dropped freely from the jacket into the boiler, the jacket being part of the boiler.

The question of steam-jacketing seemed to him clear enough. A slow engine would not do without it, and a fast engine would do very badly without it, but not so badly as a slower. The sole point was the speed of the piston; the higher the piston speed, the more power was got out of the engine for the same supply of heat from the jacket, and therefore steam-jacketing became slightly less important.

(Mr. David Greig.)

In at least a hundred experiments which he had carried out on this subject the results had come out about the same: when the steam-jacket was off, which was managed by keeping the steam out of it, there was a loss of about 7 per cent. in fuel.

The success of a compound engine—whether locomotive or otherwise—depended in a great measure on keeping the steam up to its temperature in the low-pressure cylinder; and he fully believed that any compound engine not steam-jacketed was a mistake as far as compounding was concerned. The moment the steam-jacket was turned off, it would be seen that condensed water was at once discharged from the low-pressure cylinder.

The discrepancy which had already been commented upon, between the economy in steam and in fuel with the compound engine in Mr. Borodin's experiments, page 338, seemed to him rather surprising; and he should be glad to hear something more about it. In his own experiments he had found that the percentage of saving in water and in coal, as a consequence of the use of steam-jackets, was identical; whereas Mr. Borodin had given one percentage for the saving in water and another for that in fuel. It was a pity in his opinion that these experiments had been carried out under such unfavourable circumstances in regard to boiler pressure. No gain whatever he considered could be got from a non-condensing compound engine working with only 70 or 80 lbs. pressure. The boiler pressure ought to be not less than 150 lbs., and if possible it ought to be higher still; because as the pressure increased, so also did the gain from compounding.

Mr. THOMAS URQUHART did not gather from Mr. Borodin's paper whether the steam-jacketing was done by fresh steam direct from the boiler, or by the exhaust steam. If by fresh steam from the boiler, did the jacket itself form part of the steam-pipe, so that all the steam from the boiler should pass first through the jacket on its way to the valve-chest?

In pages 321 and 350 of Mr. Borodin's paper the conclusion was stated that it was not economical to work locomotives with cylinders of too large size. This seemed to him to contrast strongly with the

practice of locomotive engineers in England, who endeavoured to get the cylinders as large as possible in area, utilising the whole width available between the frames.

From the papers of Mr. Borodin and Mr. Sandiford it was clear that the compounding of locomotives was a subject which still demanded the closest attention. Conflicting opinions were still entertained as to the real profit resulting. On the Grazi and Tsaritsin Railway in South Russia he was now about to alter one six-wheel coupled goods locomotive to the compound principle on M. Mallet's plan, in order to test its real utility; and when the results were sufficiently ascertained, he should have much pleasure in communicating them to the Institution.

The primary conditions which he considered essential in a compound locomotive were the three following :—firstly, simplicity; secondly, a tractive force of not less than one-sixth of the adhesive weight when working in full gear; and thirdly, an economy of at least 10 per cent. in fuel, in comparison with ordinary locomotives having the same adhesive weight. For a less saving than 10 per cent., he thought it would not be worth while to compound a locomotive.

Mr. Henry Carrick, having formerly been connected with Indian railways, could bear out what had been said by Mr. Brook-Fox as to the extreme value of any economy that could be effected in fuel consumption in that country, as indeed in any other. In those parts of India that were distant from coal-fields, the rate paid for fuel was excessively high. In regard to the mode of compounding carried out by Mr. Sandiford in the four-cylinder locomotive Vulcan, he would strongly support what Mr. Urquhart had said, that simplicity ought to be the great point thought of in compounding; because the more the working parts were increased, the more were also the difficulties increased of keeping them in order.

Mr. J. A. F. Aspinall observed that in Mr. Borodin's paper great stress had been laid upon the advantage of having what he called a locomotive testing shed. Such experiments however as had here

(Mr. J. A. F. Aspinall.)

been conducted seemed to him to be hardly as valuable when tried in a shed as they would be when tried outside, especially with regard to steam-jacketing, because in a shed the engine was not and could not be under the same varying conditions that it was under upon the road. Whatever results therefore were obtained in the shed must be of inferior value as compared with the actual work done in running upon a railway: besides which the engine, as had been pointed out, had been exerting in the shed a very small proportion only of its full power.

In Mr. Sandiford's paper attention was directed to a matter which he thought was of great importance, namely facility for changing engines from compound to non-compound or conversely. In regard to this point it was remarked on page 357 that "where compound engines can be built completely new, with every advantage in original design, these considerations may seem less important; but elsewhere their force will be felt, and it will be readily understood why the designs in the present instances took the particular forms here described." In dealing with new engines there was but little difficulty in making a compound engine either in one form or another. But locomotive engineers had not to consider new engines only; they had in some cases a very large number of existing locomotives, and if it was worth while to build a new engine upon the compound principle, it was worth while to look forward to altering the old ones to compound. If this were to necessitate changing the crank-axles, and possibly altering the frames and making other extensive alterations, it would add greatly to the cost of the conversion, and very likely run away with a great deal of the profit which might otherwise be realised if the engines could be altered very simply. It would be seen from the drawings that both the engines altered by Mr. Sandiford were for the Indian 5 feet 6 inches gauge; and in that respect the author had enjoyed a considerable advantage, because he would presumably have something like 4 ft. 10 ins. between the frames, and could therefore get very large cylinders in between the frames comfortably, while keeping the steam-chest in the ordinary position between the cylinders. That was not a facility which would be met with upon an English

railway; for with only the 4 ft. 8½ ins. gauge it was difficult enough to get the ordinary cylinders in for ordinary locomotives, and the difficulty would become much greater if it were tried to compound them and to get still larger cylinders in.

With reference to fuel, it had been pointed out how expensive it was in India; and it was also too expensive on many lines in England. The railways running south of the Thames, and others like the Great Eastern, had to pay a great deal more for their coal than those running through the northern districts and through coal-fields; and if it was now turning out to be an economical thing for any one of the great railways running north from London to compound its engines, it ought to be a still more economical thing for those to do so who had to pay a much higher price for their coal.

Some mention had been made of steam-pipes, and it had been pointed out by Mr. Halpin that it was desirable to have them as large as possible. In recently trying some experiments upon a locomotive in connection with another subject, he had himself found that there was a very great difficulty in getting the steam to flow fast enough through a 3½-inch pipe to keep the steam-chest full of steam at boiler pressure. His experiments had been tried with a goods engine with 18 by 24 inch cylinders, running at no more than between ten and fifteen miles an hour; and he found that when working up to the full power it was impossible to get the 140 lbs. boiler pressure in the steam-chest, notwithstanding that the engine was running at so slow a speed. In order to make the experiments which he was trying more valuable, he put in a 4-inch steam-pipe, and then found a gain of about 20 lbs. per square inch in the steam-chest pressure. Later on the same experiments were repeated with the 4-inch pipe when running at about thirty miles an hour, and he again found a very considerable diminution of pressure in the steam-chest. In these experiments it had been necessary to work up to the full power; and in this respect of course the engine might be working under conditions under which it would not ordinarily have to work. Nevertheless the loss of pressure in the steam-chest was an interesting fact, which he thought worth mentioning.

Mr. T. HURRY RICHES observed that on the subject of consumption of fuel there seemed a lack of information in Mr. Sandiford's paper, as regarded the compound engines; and he should be very glad if Mr. Sandiford would add that information. It was true that on page 360 the consumption per vehicle per mile with the ordinary non-compound engines was stated to have amounted to 1·17 lb. with Bengal coal, 1·07 lb. with Ebbw Vale coal, and 0·98 lb. with Crown patent fuel; the latter he had himself used, and he knew it to be exceedingly good, and it would not be subject to much deterioration from the voyage out. From other figures in the same Table it also appeared that the average weight of train, including engine and tender loaded, was 256 tons nearly for the Crown fuel and 260 tons nearly for the Ebbw Vale coal, while the consumption per mile was stated to be 26·54 lbs. and 29·99 lbs. respectively; hence the consumption per ton per mile would be with Crown fuel 0·104 lb. and with Ebbw Vale coal 0·115 lb. These therefore were not by any means good results; in fact the consumption was above the average; and therefore, even if the compound engines showed 13½ per cent. economy upon these figures, their consumption would still be a good deal above the average practice upon English lines. He quite endorsed what had been said by Mr. Aspinall as to the greater breadth of the Indian gauge enabling Mr. Sandiford to get larger cylinders in, while still keeping the valve-chest between them; but of course on the 4 ft. 8½ ins. gauge larger cylinders would necessitate placing the valves on the top or beneath, the latter by preference.

In reference to Mr. Borodin's paper, with which, owing to its voluminous character, he much regretted not having the time to deal more fully, he would remark, as to the draining of the steam-jackets, that he had found for draining steam-pipes having a long lead it had been an advantage to employ a float valve, which was not dependent, as the steam-trap was in Fig. 7, Plate 67, upon the temperature, but upon the height of water, so that the float would open the valve for discharging the water immediately on the water rising above a certain height. This plan he had always found to work efficiently in getting rid of condensation in steam-pipes.

In regard to the advisability of trying a fan on a locomotive, as suggested by Mr. Rich, that experiment was one he had tried some years ago, using various blowers in connection with a forced draught. In one trial that he had carried out for three or four months with a fan and a closed ash-pan, he found that, although what was otherwise unburnt residue in the fire-box was thereby practically got rid of, and there was literally no cinder or ashes remaining at the end, yet there was only a very small percentage of improvement under the head of coal consumption. After that prolonged trial therefore he abandoned the further little complication of putting fans on. Other methods of forced draught he had also found would burn up all that was in the fire-box; but there was not a corresponding saving in the consumption.

Mr. E. H. Carbutt was glad to call attention to the unusual circumstance of their having listened to two papers on compound locomotives, one written by a member who had made experiments in Russia, and the other by a member who had made experiments in India. As an Institution they were delighted to have the experience of their fellow-engineers all over the world. While cordially welcoming both papers alike, he would take the opportunity of mentioning that Mr. Sandiford's was he believed the first locomotive paper that had been read in the Institution by an engineer from India. The fact should be remembered that in the Indian possessions there was a population of 250 millions, and that a very large number of engineers were doing good and grand work there for this country and for the Indian population. Indian railways were constructed by the Public Works Department, which employed something like 750 civil engineers and 250 military engineers. He had himself been mainly instrumental in obtaining the Committee of the House of Commons, which was appointed some two years ago to consider the construction of railways in India; and from the evidence as to the requirements of India which was placed before that Committee, they all came to the conclusion that the only way to develop India properly, and to prevent famine, and to put the Indian population in a proper position, was that the railways of the country

(Mr. E. H. Carbutt.)
should be materially increased. The Indian railways were constructed on a different system from that adopted in this country: a large amount of the necessary funds were supplied out of the revenues of India; other railways were also constructed with money guaranteed by the Indian government. That guarantee system was a heavy drain upon the government; and therefore anything which materially reduced the working expenses of railways in India would no doubt conduce materially to the construction of further railways. The Committee had come to the conclusion that the right thing to do was to give the Indian government power to expend six or seven millions a year on increasing the railways in India, but with this proviso—that they must be all self-supporting, or at any rate the estimates put before the government must show them to be self-supporting. If therefore the cost of working could be materially reduced, no doubt the Indian government would go on spending more upon construction. There were a large number of railways at the present time being made in India; but unfortunately some of them were for warlike purposes, such as the Quetta Railway. One railway which was greatly needed was a line across from Bombay to Calcutta; when that was made, a very large quantity of grain would be brought to the different ports. Until within the last few years no grain whatever had been exported from India to this country; but at the present time one-third of the grain received in this country came from India. Everything showed in his opinion that the railways had been a great benefit to India; and therefore he was quite sure that the members would all share the satisfaction with which he had listened to Mr. Sandiford's paper upon compound locomotives in India. He was also glad they had heard something in the present discussion from Mr. Brook-Fox, one of the executive engineers in the Indian state railway service.

Mr. T. R. Crampton mentioned that prior to 1840 he had gone into the question of compounding, in conjunction with the late Mr. Edward Humphrys, at whose works experiments were made with various pressures of steam up to a moderate limit, with and without steam-jackets, and with superheated steam not only inside

the cylinders but also in the jackets. The conclusion he then came to was that there was not very much to be gained commercially by going beyond about 60 lbs. or 70 lbs. pressure of steam and an expansion of six or seven times. From experiments made in France and Germany that conclusion seemed to him to be not very far from correct, looking at the commercial aspect of the subject. In testing the value of steam-jacketing in his own early experiments he had found that no better result was gained from compounding with unjacketed cylinders than from expanding the same number of times in a single cylinder properly steam-jacketed. The advantage of steam-jacketing became thus so palpable to his own mind that he designed the arrangement shown in Figs. 64 and 65, Plate 88, for locomotive cylinders; and in 1857 six locomotives were built by Messrs. Hawthorn according to that drawing, with jacketed cylinders of 16 inches diameter and 22 inches stroke, the jackets being properly drained. The London Chatham and Dover Railway was opened with those six engines, which also had flat tires on all the wheels; at that time his view was that 140 lbs. steam expanded four or five times in locomotives was the commercial limit. That was the earliest instance he knew of steam-jacketing locomotive cylinders; and he had heard no more of the subject from that time until now, when it was no small pleasure to him to find a member of the Institution coming from Russia with a paper in reference to it. The plan proposed by Mr. Halpin for draining the jackets by means of an injector seemed a good one. As to increasing the size of locomotive boilers, his own impression was that a marine boiler properly constructed would, under most circumstances, prove the best possible boiler for locomotives. A marine boiler he thought might be made for locomotive use with 1500 square feet of heating surface within a distance of 12 feet between the driving axles, with 10 per cent. less weight than any other locomotive boiler at present in existence. The value of outside cylinders and outside gear, and the direction in which the power was given out from the cylinders, and the side strains upon the wheel flanges in working, were all points deserving of still further investigation in connection with locomotive engines.

Mr. BENJAMIN WALKER said that more than thirty years ago he had tried careful experiments with steam-jacketing with a pair of large beam-engines made at the Bowling Iron Works with a maximum pressure of 44 lbs. per square inch. The engines were driving an oil mill, and the work was very uniform, going on day and night; the opportunity was therefore a very good one for testing the value of the steam-jacket. The engines worked for weeks together without the jackets, and for weeks with, doing precisely the same work; and it was proved beyond dispute that more work could be got out of the engines with the steam-jackets than without, and there was also some economy of fuel. Since then he had met with nothing that had altered his opinion. In experiments that he had tried with high-pressure steam, he had found that the jacket was a great advantage, first as a source of economy, and secondly because more work could be got out of the same engine with jacketing than without it; from 10 to 15 per cent. more work could be got by applying the steam-jacket properly.

With regard to compounding, there could be no doubt about its value when applied to ordinary mill or marine engines. Its value when applied to the locomotive was not so definitely and clearly settled. In this country Mr. Webb, Mr. Dean, and Mr. Worsdell were occupying themselves with this matter; and he had no doubt they would sooner or later find out how to make a locomotive on the compound or else on the triple system that would be more economical than the ordinary locomotive. On the other hand Mr. Stirling and Mr. Stroudley had made up their minds at present that the compound locomotive was not the best; but he believed the day would come when they would see reason to alter their opinion. The value of compounding began at a comparatively low boiler-pressure; and he believed steam of even as low as 80 lbs. pressure could be worked on the compound principle with considerable economy over the ordinary single cylinder. The tandem arrangement he thought was the best for a locomotive engine; and in any case the steam should not be allowed to go direct from the smaller cylinders into the larger, but should exhaust from the high-pressure cylinders into a Cowper's hot-pot or heated receiver, in order that the low-pressure

cylinders might then receive their steam as hot as possible, as if it came direct from another boiler. The extent of expansion between the high and the low-pressure cylinders he considered should be in proportion to the relative sizes of the two cylinders; and this proportion should vary with the pressure of steam in the boiler.

A good deal had been said about the friction brake for testing engines; and he thought Mr. Halpin deserved credit for the way in which he had called attention to the subject. Having lately been carrying out some elaborate experiments, with a view of testing the relative value of air and water for conveying power to a considerable distance, he had not thought it advisable to use a brake or an indicator diagram, but had raised and lowered a heavy weight as was done in a crane, measuring both the lift and the load, and thus obtaining so many foot-tons of work done by so many revolutions of the engine. That was a plan which he much preferred to the ordinary friction brake and indicator diagram.

Mr. Druitt Halpin observed that in page 359 of Mr. Sandiford's paper it was stated that in the original crank-axles of either engine no weakness had been perceived as a consequence of the increased power from compounding. The crank-axle was subject to only two stresses, namely the weight of the engine as a carriage, and the stress due to the steam. The former was not increased by compounding, inasmuch as the extra weight was all thrown on the leading wheels; and the stress due to the steam was diminished by compounding. Hence he did not see how any injurious effect upon the crank-axle could be anticipated from compounding. It was also remarked in page 359 that the eccentrics had been found large enough to drive two sets of valves instead of one. But if it was remembered that the valves in the compound engine were working under only the difference of steam pressures in the two cylinders, instead of under the full boiler-pressure, it would be evident that there was not such a very great increase of work thrown on them as might appear at first sight.

With the remark in pages 357–8 about coupling-rods he could not agree, because he considered one of the great advantages in

(Mr. Druitt Halpin.)

compounding was the possibility of doing away with the coupling of the wheels. There was independent testimony, unfortunately slight, but concurrent on both sides of the Atlantic, that a coupled engine was one of the most wasteful machines known. Experiments on the Eastern Railway of France gave a net result from coupled engines that no more than 42 or 43 per cent. of the power indicated in the cylinders was developed on the drawbar; and recent experiments made in America, with four-coupled engines having 18 × 24 inch cylinders, gave exactly the same useful percentage. It seemed evident therefore that coupling did a large amount of harm by absorbing power, because the efficiency of uncoupled locomotives was well known to be very much higher.

The plan of compounding locomotives with only two cylinders of unequal diameter seemed to him unsatisfactory. Provided the work to be done was constant, that was no doubt the most natural plan; but as the work was always varying, it was impossible to get uniformity of power with only two cylinders; and if uniformity of power was not obtained, the benefits which might otherwise be hoped for were to a great extent sacrificed.

The cost of fuel had no doubt much to do with the question of compounding locomotives in India; but if the government of India had permitted the original Scinde Punjaub and Delhi Railway to construct the Indus Valley line and so to carry their line right through to a port without break, it would have paid as well as any. For burning wood on the Punjaub and Delhi Railway he remembered there were five men to each engine, a driver, a stoker, and three extra native firemen, with an extra wagon behind from which the men had to supply the wood for firing. To get over that difficulty the government sent a geologist up to one of the hill ranges, to search for coal. He found what he called coal, and 50 tons were sent to Lahore at some very high cost. Nothing could be done with it however in the locomotives; and it was ultimately used as ballast for the permanent way.

The results given in Mr. Sandiford's Table as obtained from the Ebbw Vale coal he agreed with Mr. Riches were low in economy; but it must be borne in mind that coal underwent great deterioration

when transported in ships to India, in consequence of the severe action of the climate and the disintegrating effect of the voyage.

In the injector arrangement shown in Fig. 59, Plate 87, for draining the steam-jackets, there would of course be a cock inserted at a suitable place for regulating the amount of discharge from the jackets and keeping it under perfect control.

Mr. William Anderson, Erith, sent the following remarks, which he was prevented from making verbally in connection with Mr. Borodin's paper by the closing of the discussion through want of time:—

"In the first place, respecting the relative economy in using single or compound engines, it is strange that engineers seem to continue to ignore the great doctrine of Carnot, that the efficiency of a heat engine depends upon the ratio which the fall of temperature in the working substance bears to its original absolute temperature. Steam engines working under various initial and terminal pressures—and therefore temperatures—cannot be compared without due allowance being made for the varying ranges of temperatures through which they work. Suppose a single water-wheel actuated by a 10-ft. fall were placed in competition with a pair of water-wheels utilising in succession the same quantity of water per minute but with a total fall of 15 ft., the compound arrangement would most likely do more work for the same expenditure of water; but no one would infer from that circumstance that the compound arrangement was more efficient than the single wheel, because it would be observed that the fall in the compound case was 50 per cent. greater than in the single. The steam engine works under precisely similar conditions. In the case of the simple and compound locomotives, the former appears to have been tested under 75 lbs. absolute pressure and 767° Fahr. absolute temperature, and the latter under 113 lbs. absolute pressure and 797° temperature. If we suppose the exhaust steam in both cases to escape at about $1\frac{1}{2}$ lbs. pressure above atmosphere and 676° absolute temperature, Carnot's principle will give a possible duty of $\frac{767-676}{767}=0\cdot119$ for the simple engine, and $\frac{797-676}{797}=0\cdot152$ for the

(Mr. William Anderson.)

compound, or a gain of 28 per cent. for the latter. The actual advantage realised in Mr. Borodin's experiments (page 323), of only 17 per cent. in the compound engine, points to a fact, which may be inferred from theory, that, irrespective of all practical considerations, the use of steam in a single cylinder is more advantageous than in a compound arrangement.

"In the second place, with regard to the steam-jacket, an examination of indicator diagrams will show that the expansion curve is that derived from Boyle's law; it is in fact the isothermal curve, upon the properties of which is based the formula for calculating the mean pressure in cylinders working expansively. Consequently the temperature of the steam must remain nearly constant throughout the stroke; and hence the heat converted into work must be derived from other sources than from the cooling of the steam. The truth is that steam, working in an unjacketed cylinder, has two duties to perform: it has to act as the agent whereby heat is converted into work, for which purpose air or any other gas would do as well; and in addition it has, by the condensation of a small part of itself, to provide the heat which is so converted into work. Whereas, in an efficiently steam-jacketed cylinder, the steam within the cylinder has only the duty of agent to perform, while the heat which is converted into work is derived from the condensation of the steam in the jacket; and it will oe found that the water draining from the jackets has yielded almost exactly the amount of heat which corresponds with the work done. Consequently, as very clearly put by Mr. Walker (page 398), the advantage of a steam-jacket is that it enables the same engine to do more work; because it enables that portion of the steam which acts merely as agent to be worked to greater advantage by superior expansion. The reason why there is so much doubt about the efficiency of jackets is, because they can effect only a very small saving in a fraction only of the heat which is actually converted into work. Hence comparative trials are often inconclusive, because small defects and variations mask the effects of the jackets.

"The advantages of compound expansion, when high-pressure steam is used, are incontestable, because it is impracticable for the rate of expansion required by high-pressure steam to be adopted in a single

cylinder, and indeed often in a compound engine; but the economy resulting is due to the increased range of temperature through which the steam works, and not to any advantage in the mechanical arrangements by which it is worked."

Mr. Borodin, in reply to Mr. Davey's enquiry (page 372), stated that the ends of the cylinders were jacketed, as well as the barrel.

In answer to the questions asked by Professor Kennedy (page 376), firstly, the discharge of condensed water from the steam-jackets took place automatically through the trap while the experiment was in progress; but as soon as ever the experiment was ended, the trap was then fully opened for collecting all the water from the jackets. Secondly, during the train trials the cylinders were covered with wood lagging and sheet iron; but during the experiments in the testing shed they were not covered. Thirdly, the water from the overflow was measured separately. Fourthly, the mode of measuring the feed-water in the train trials was the following. Before starting from each station the water-level in the tender was noted by the two gauge-glasses on the sides of the tender, and the mean of the two readings was taken for determining the quantity of water in the tender at starting. On stopping at the next station, the small vessels of known capacity, mentioned in page 324, for catching the overflow from the injectors, were first filled up full with water from the tender through the injector cock, and then the water-level in the tender was again noted. The difference between the quantities of water in the tender at starting and at stopping, minus the small vesselfuls, represented the quantity of water fed into the boiler. By noting also the water-level in the boiler both at starting and at stopping, the necessary corrections could be made for determining the exact consumption of water during the run.

The arrangement of the indicator pipes in these experiments had been copied from that in Herr Bauschinger's well known indicator experiments with locomotives, and was the same as recommended by Mr. Forney and other writers upon the steam engine. The length and bending of the pipes would of course have some influence on the indicator diagrams; but that this influence was of no very

(Mr. Borodin.)

serious nature might be inferred from the growing use of steam-power meters or continuous indicators, such as Boys' or Ashton's meters, which necessarily had pipes not shorter and not less bent than those used in these experiments; such instruments would certainly be of no value if they involved errors of 38 per cent., as in the instance mentioned by Mr. Halpin (page 364). Errors of that magnitude might perhaps be possible with very quick running engines, if the pipes were left unprotected, and were of too small diameter and too long and too much bent. In his own experiments the pipes had been well clothed; and that they had involved no serious error was clearly seen not only from the character of the indicator diagrams themselves, but also from the consumption of steam shown in Table 10, page 337, which for the compound engine was only 22 lbs. per indicated horse-power per hour for an expansion of 4·5 times, and even went down to 19·95 lbs. for an expansion of 6·7 times. It seemed therefore unreasonable to suppose that the indicator diagrams could be even so much as 20 per cent. too small in consequence of the pipes being too long, because such an error would reduce the consumption to only 17 or 16 lbs. per I.H.P., which would be lower than could be expected from a non-condensing engine: were there even an error of only from 5 to 10 per cent., that would give too low a consumption. Furthermore, inasmuch as any influence of the pipes would be more or less the same on the ordinary and the compound locomotive alike, whether working with or without steam-jackets, it could have no marked effect upon the comparative results or upon the conclusions drawn from the tests.

On page 353 he had expressed the opinion that "a better means of draining the steam-jackets must be sought for," the draining of them having been imperfect in his experiments. While criticising the steam-trap used for the purpose in these tests, M. Vinçotte had mentioned (page 387) that he had not hitherto seen any device for draining jackets which was reliable in its action. A float-valve, as recommended by Mr. Riches (page 394), would scarcely be applicable for a locomotive running at twenty to sixty miles an hour. A new and seemingly ingenious method for draining steam-jackets by means of injectors had been proposed by Mr. Halpin (pages 365–6), in which

the necessity of some sort of valve or trap between the injector and the jacket had been pointed out by M. Vinçotte; and Mr. Halpin had explained (page 401) that there would be a cock inserted for regulating the amount of discharge from the jackets. But how such a plan would practically work, whether it would be applicable to a locomotive, and whether it would satisfy the condition of simplicity that was so essential for locomotives, was a question yet to be decided by actual trial. Perhaps the best solution of the problem would be to make the steam from the boiler circulate first through the jackets on its way to the valve-chest; and this arrangement he was now preparing to test.

With the opinion expressed by Mr. Halpin (page 365) that all steam-jackets must be condensers he could not agree as representing the proper meaning of his own use of the word condensers in page 353 of the paper. There was an essential difference between jackets and condensers, the jackets being applied to an engine for the purpose of heating the steam in the cylinders, while the condensers were for cooling it.

In reference to Mr. Greig's remark (page 390)—that "it was a pity these experiments had been carried out under such unfavourable circumstances in regard to boiler pressure," no gain being got from a non-condensing compound engine working with only 70 or 80 lbs. pressure—it would be seen from Table 9, page 333, that all the train trials were conducted with a boiler pressure of 100 to 133 lbs. above the atmosphere.

The doubt expressed by Mr. Halpin (pages 370–1)—that "there must have been something radically wrong" in the experiments in which the initial pressure in the cylinders was stated on page 331 to have gone down to as low as only 53 per cent. of the boiler pressure—had been rightly dealt with in Dr. Ryan's remarks. It was mentioned in page 325 that the engine drawing the experimental train was kept working during the whole of the test with the reversing lever in the same notch; the boiler pressure was also kept the same, so that the engine should exert a nearly constant power, which was only the minimum power necessary to draw the train on the experimental section of the line, any extra power being provided

(Mr. Borodin.)

by the pilot engine. When experimenting with too large admission, as was the case in tests 11*b* and 12*a* with the ordinary engine working in notches 7 and 11 respectively, giving an admission of about 70 to 80 per cent., it was found that if the engine worked with the regulator fully open it exerted too much power; and consequently in those tests, as shown in column 15 of Table 9, page 333, it was necessary to diminish the opening of the regulator in order to reduce the initial pressure in the cylinders until it was only 55 and 53 per cent. of the boiler pressure, as stated in page 331. When working with the regulator fully open, the initial pressure in the cylinder was 95 per cent. of the boiler pressure, and sometimes more. In analysing the results obtained, all the experiments were put aside that had been made with the regulator openings too small, as mentioned in page 331; and only those tests were compared in which there was no considerable loss of pressure.

In reply to Mr. Urquhart's question on page 390 concerning the manner of steam-jacketing, the jackets were supplied with steam direct from the boiler through special pipes, as mentioned in page 305.

In regard to Professor Kennedy's remark on page 377—that it was assumed in page 304 of the paper "that practically all the steam condensed in the jackets had been condensed by giving up its heat to the steam inside the cylinders"—it would be seen from page 304 that the assumption actually made was that the steam condensed in the jackets gave up to the steam inside the cylinders not all its heat, but only the part $h = m\,(606\cdot5 + 0\cdot305\,t_2 - q_2)$, while the other part R_e of its heat was lost by the external cooling. The value assumed for R_e—of $0\cdot5$ caloric $= 1\cdot98$ British thermal unit for each cylinder and each revolution—was so small in comparison with the whole quantity of heat supplied by the boiler, that a small error in R_e could have no influence on the calculation of the quantity of water carried over by the steam; but the value of R_e was not at all small in comparison with the quantity of heat h going to the steam inside the cylinders; it was indeed about 55 per cent. of that quantity. For instance, in test No. 15, $h = 13578$ calories, $R_e = 7446$; in No. 16, $h = 19189$, $R_e = 10833$; in No. 22, $h = 20515$, $R_e = 10205$ calories; and so on.

Respecting Mr. Anderson's calculation (pages 401–2) of a gain of 28 per cent. to be expected from the compound engine in conformity with Carnot's principle, as compared with an actual advantage realised of only 17 per cent.—it would be seen from page 323 and from Tables 5 to 7 that the economy of 17 per cent. in the compound engine resulted from tests made on the ordinary engine on the 16th of September and the 21st of July 1881, in which the absolute boiler-pressure, instead of being 75 lbs., was 94·5 lbs. and 106·1 lbs. Moreover on page 338 it would be seen that a gain of from 20 to 32 per cent. had been found for the compound engine working through the same range of expansion and temperature as the ordinary engine. If it was possible that engineers sometimes ignored the great doctrine of Carnot, it was hardly to be supposed that investigators basing their researches upon the mechanical theory of heat would forget Carnot's principle. The relative economy of compound engines was probably due only to the diminished condensation of steam in the cylinders, quite independently of Carnot's principle.

The discrepancy commented upon by Dr. Ryan and Mr. Greig, between the economy in steam and in fuel with the compound engine, had been dealt with in page 353 of the paper, and he had as yet nothing further to add on that point.

With regard to Mr. Aspinall's remark (pages 391–2) that experiments conducted in a locomotive testing shed were not so valuable as they would be when the locomotives were tried outside, he still retained the opinion that reliable tests, duly checked, could be made only in a shed properly fitted up. Throughout the whole world there were probably a larger number of locomotives than of stationary engines, and the locomotives consumed more fuel than the stationary engines. Nevertheless, while stationary engines—ordinary, Corliss, compound, jacketed and unjacketed—had been the subject of so many interesting and thorough and altogether scientific investigations, there were hardly any similar investigations in regard to locomotives, which were so different in their higher steam-pressure of 120 to 130 lbs. above atmosphere, and in their use of single slide-valves worked by link-motion, as well as in other respects. Moreover locomotives

(Mr. Borodin.)

themselves were of very various kinds—American, English, French —with boilers, fire-boxes, and valve-gear of very various construction; and no definite idea had yet been arrived at, as to which of all these constructions was the best. On the question of fuel consumption in locomotives, much uncertainty still prevailed; in default of scientific investigation and accurate data, the working returns were commonly the sole source of information; and from these had often been drawn misleading conclusions. In this way an economy of 30 to 35 per cent. had recently been calculated for compound locomotives; but such a result was being questioned at the present time, and there was no knowing what to believe on the subject. The real source of difficulty was that the consumption in running depended on a variety of disturbing circumstances, which interfered with the accuracy of the results. These were the reasons why he wished, in conclusion, to repeat that, if locomotive engineers would make careful tests with locomotives in testing sheds properly fitted for such purposes, as was done in the case of stationary engines, and would not base their conclusions upon the consumption per train-mile or per ton-mile, which gave no reliable data, much light would thereby be thrown upon many questions at present unsettled, and real progress in locomotive working would be the result.

Mr. SANDIFORD wrote from India that the answer to Mr. Riches' enquiry (page 394) about the consumption per ton per mile by the compound engines was found in pages 356 and 357 of the paper, where the performance by the Vampire was given at 33·10 lbs. of Bengal coal per train-mile with a gross load of 489 tons, equivalent to 0·068 lb. or about 1–15th of a pound per ton per mile; and by the Vulcan 33·13 lbs. of the same coal with a gross load of 520 tons, equivalent to 0·064 lb. or about 1–16th of a pound per ton per mile. The figures given in the Table, pages 360–1, to which reference had been made by Mr. Riches, were those obtained with ordinary locomotives, not compound.

In discussing coupling-rods it had been remarked by Mr. Halpin (page 400) that only 42 to 43 per cent. of the cylinder power was

given off at the drawbar. It would be interesting to know how much of the loss was due to the side-rods : very little, he believed.

The President observed that in the present discussion on compound locomotives there had been differences of opinion as to the value of the steam-jacket and as to the value of high pressures. Although he thought there had been a strong preponderance of opinion in favour of the steam-jacket and also in favour of high pressures, there had been a striking unanimity in favour of a regular set of scientific experiments for determining accurately the value of the steam-jacket. Another point on which he was sure there was perfect unanimity was that the best thanks of the meeting should be given to Mr. Borodin and Mr. Sandiford for the very able papers they had contributed, which had given rise to so interesting and valuable a discussion.

EXCURSIONS.*

On Tuesday Afternoon, the 17th of August, after luncheon in the Westminster Town Hall, by invitation of the Local Committee and their friends, one party of the Members visited the Royal Mint, by permission of the Deputy Master, the Hon. C. W. Fremantle, C.B., (page 413). An Excursion was made by another party to Chelmsford to visit Messrs. Crompton and Co.'s Electric-Light Works (pages 413–14). A third party visited the Lambeth Pottery of Messrs. Doulton and Co. (pages 414–16).

In the evening the Members visited the Colonial and Indian Exhibition, South Kensington, by invitation of the Local Committee and their friends. By special permission of H.R.H. the Prince of Wales, K.G., a reception was held in the Conservatory by the President and the Chairman of the Executive Committee.

A number of Works &c. in London, of which a list is given on page 412, were opened to the visit of the Members on the afternoons of both Tuesday and Wednesday. Descriptions of various of these Works are appended (pages 417–426).

On Wednesday Afternoon, the 18th of August, after luncheon at the Midland Grand Hotel, St. Pancras Station, by invitation of the Local Committee and their friends, an Excursion was made by special free train to Enfield, to visit the Royal Small Arms Factory (pages 428–440), by permission of the War Office, and under the guidance of the Superintendent, Colonel Arbuthnot, R.A.

In the evening the Institution Dinner was held at the Criterion, Piccadilly, the President occupying the chair, and was largely attended by the Members and their friends. The whole of the Belgian Engineers were invited, as well as a number of other guests. The toast of the King of the Belgians having been drunk next after that of the Queen, a letter of acknowledgment was subsequently sent from Brussels by command of His Majesty.

---

* The notices appended of the various Works &c. visited in connection with the meeting were kindly supplied for the information of the Members by the respective proprietors or authorities.

On Thursday, the 19th of August, an Excursion was made by special free steamer, by invitation of the Local Committee and their friends, to Woolwich and Beckton. At Woolwich the Royal Arsenal was visited, by permission of the War Office (pages 440–441), the arrangements for the visit having been made by the Superintendents of the manufacturing departments, Colonel Close, R.A., Colonel Maitland, R.A., and Colonel Barlow, R.A. Proceeding thence to Beckton, the Members visited the works of the Gas Light and Coke Company (pages 442–7), where they were entertained at luncheon by invitation of the Directors of the Company. In returning to London through the Royal Victoria and Albert Docks (pages 447–450), by invitation of the Directors of the London and St. Katharine Docks Company, they inspected the frozen-meat storage arrangements described by the General Manager, Colonel Martindale, C.B., R.E., at the previous meeting (Proceedings 1886, page 242).

In the evening the Members again visited the Colonial and Indian Exhibition, South Kensington, by invitation of the Local Committee and their friends, where, by special permission of H.R.H. the Prince of Wales, K.G., the Conservatory was reserved for their reception. The Electric Lighting Machinery in the Exhibition was inspected (pages 426–7), by invitation of the Chairman, Sir Frederick Abel, C.B., and the Members of the Electric Lighting Committee. The Queensland Gold Quartz Mill was also shown in operation (pages 427–8).

On Friday, the 20th of August, an Excursion was made by special free steamer, by invitation of the Local Committee and their friends, to Tilbury, Crossness, and Poplar. At Tilbury the new Docks were visited of the East and West India Dock Company (pages 450–2), under the guidance of the Secretary and General Manager, Colonel Du Plat Taylor; and the Members were entertained there at luncheon by the Local Committee and their friends. A special train conveyed to Fenchurch Street Station those who wished to visit, on the invitation of the Engineer and Manager, Mr. Arthur L. Stride,

the large Depôt and Warehouses now building there by the London Tilbury and Southend Railway.

In the return by steamer from Tilbury, several of the Members landed at Crossness to visit the Southern Outfall Sewage Pumping Station (pages 452–6), on the invitation of the Engineer to the Metropolitan Board of Works, Sir Joseph W. Bazalgette, C.B. The rest, proceeding to Poplar, visited the works of Messrs. Yarrow and Co. (page 457), and the London Yard Iron Works of Messrs. Westwood Baillie and Co. (pages 457–9).

In the evening the Members were invited to visit the Electric Lighting installations at the Great Western Railway Station, Paddington; the London and St. Katharine Docks; the Prince's Theatre; the Criterion Restaurant; and the Holborn Restaurant.

WORKS IN LONDON

OPENED TO THE VISIT OF THE MEMBERS.

Maxim Automatic Machine-Gun Works, 57D Hatton Garden.

General Hydraulic Power Co.'s Central Pumping Station, Falcon Wharf, Holland Street, Blackfriars; Auxiliary Pumping Station, 2 Philip Lane, Wood Street, Cheapside; Special Pumping Station, Kensington Court, Kensington High Street.

Locomotive Works of the Great Eastern Railway, Stratford.

Locomotive Works of the London Chatham and Dover Railway, Wandsworth Road.

Goods Station of the London and North Western Railway, Broad Street.

Goods Station of the Midland Railway, Whitecross Street.

National Agricultural Hall, Addison Road Station, Kensington.

Anglo-American Brush Electric Light Works, Belvedere Road, Lambeth.

Messrs. Barclay Perkins and Co.'s Brewery, Park Street, Borough.

Messrs. Barnett and Foster's Soda-Water Machinery Works, 26 Eagle Wharf Road.

Messrs. David Hart and Co.'s North London Iron Works, Wenlock Road.

Sanitary Works at the Foundling Hospital, Guilford Street, Brunswick Square.

Industrial Dwellings.

Peabody Buildings.

ROYAL MINT.

The operations involved in the conversion of bullion into coin are mainly interesting to engineers from the precision with which they are conducted. The precious metals are melted with the amount of copper necessary to form the alloys prescribed by law, and are cast into bars 12 inches long and $\frac{3}{8}$ inch thick, the width varying from $1\frac{3}{4}$ to $2\frac{5}{8}$ inches, according to the coin to be produced. These bars are rolled into strips, from which discs to form the coins are cut; and to show how accurately the rolling must be performed, it may be pointed out that, in the case of the half-sovereign, a variation of 1–20,000th of an inch above or below the correct thickness throws the coin out of the "remedy," or allowance of variation in weight permitted by law. After the blanks have been brought to a definite diameter and annealed, they are automatically placed between the dies, the impression on both sides and the milling on the edge being imparted to the disc in one operation; each press strikes about ninety coins per minute. The automatic weighing machines, of which there are over thirty, divide the finished coin into "light," "heavy," and "good," at the rate of about twenty-three coins per minute in each machine; and well deserve attention as striking examples of automatic machinery.

Modern coining machinery has been gradually developed from the rough forms used in the seventeenth century, having been greatly improved by Watt, Rennie, Maudslay, and Uhlhorn: that now in use at the Royal Mint was in a great measure renewed in 1882.

ARC WORKS, CHELMSFORD.

These works were established by Mr. Crompton in 1878 for the manufacture of machinery &c. connected with the rapidly developing industry of electric lighting and electric transmission of power; they have since from time to time been extended. The main portion of the manufacture consists of dynamo electric machines, of sizes absorbing from 1 to 100 horse-power. From the class of machinery

used throughout the works it will be seen that modern electrical engineering is simply a branch of mechanical engineering, which involves the highest finish in all the parts employed, and in which a host of difficulties have to be encountered owing to the fragility of the materials that must be employed for insulating purposes. Specimens will be noticed of very large dynamo machines, driven direct by high-speed Willans engines; in careful tests these have given extraordinarily economical results, the joint percentage of power wasted in the engine and dynamo together being so small that nearly 80 per cent. of the gross power shown by the indicator diagram has been given out as the net electrical yield of the dynamo; and as the engine itself is extremely economical, the result is that one electrical horse-power can be obtained by the evaporation of 31 lbs. of water in the boiler. Large masses will be noticed of pure soft wrought-iron doubly annealed, which are for the electro magnets; and the new process will be seen of casting copper &c. required for portions of the commutators and other parts of the machines. In full work 350 hands are employed.

LAMBETH POTTERY.

The origin of the Lambeth Potteries may be traced as far back as the middle of the seventeenth century, at which period some Dutch potters settled at Lambeth. Some interesting relics of their quaint and picturesque buildings were to be seen within living memory in the district between Lambeth Palace and Vauxhall, until all were swept away by the formation of the Albert embankment. The ware made at Lambeth by the Dutch potters was chiefly Delft, although glazed stoneware was also produced at the close of the seventeenth century, and perhaps even earlier. Towards the close of the eighteenth century, the Lambeth Delft ware was confined to very humble articles; and the potteries in the district gradually became devoted exclusively to the manufacture of salt glazed stoneware, producing for the most part vessels for ordinary household purposes only.

In 1834 the establishment of Messrs. Doulton and Watts in High Street, Lambeth, consisted of about twelve persons, working two kilns a week. The progress subsequently made, slow at first though sure, and increasingly rapid during the last fifty years, has resulted in the employment at the present time of about two thousand persons at the Lambeth works alone; while the number engaged at the whole of the firm's establishments in town and country is nearly four thousand. The surroundings of the potteries in earlier years were very different from the present. A substantial residence adjoined the factory; and attached to it was an acre of garden, long since absorbed by the works, which have increased in size until the factories and studios now cover some seven or eight acres. The first important impulse was received from the application of chemistry to manufactures, whereby a growing demand was created for chemical vessels of stoneware, capable of resisting acids.

In 1846 the manufacture of stoneware pipes for the sewage of towns and for the drainage of houses was commenced by Mr. Henry Doulton, and has since developed into a most important industry. The application of machinery for the purpose was a matter of difficulty and disappointment, which was only overcome gradually; but when the difficulties of manufacture had at length been surmounted, the stoneware pipes were produced with such rapidity as to be reckoned not by feet but by miles per week; at the present time from twenty-five to thirty miles of pipes are made weekly at the firm's works in London, Staffordshire, and Lancashire, and the consumption of clay for these and other sanitary goods amounts to about 2000 tons per week.

Having in 1877 acquired works at Burslem in Staffordshire for the manufacture of the better class of earthenware, the firm have since succeeded in founding a large and increasing home trade, not only in earthenware but also in china; while their recent introductions of novel and artistic decorations have obtained for the Burslem wares a rapidly rising renown. In the new buildings at Lambeth, the manufacture of fitted sanitary wares has been greatly extended; and several important improvements in sanitary science have been

introduced, including the vacuum water-waste preventor, the automatic flush tank, and modifications in anti-percussion valves.

Apart from general and sanitary wares, the Doulton potteries have within the last fifteen years produced a large amount of art wares, and have provided an eminently suitable handicraft for female workers, in a neighbourhood where such employment was previously unknown. Until 1867 there had been no special art industry at Lambeth, beyond the manufacture of common figured jugs and of garden vases and architectural enrichments in terra cotta. In that year however, the Paris Exhibition gave the first opportunity of making a slight effort to connect art workmanship with the previously rougher productions for domestic use. At that time some fifty or sixty specimens of vases and jugs were produced. These were of simple but good forms, with slight attempts at decoration. Four years later, for the Exhibition at South Kensington, a much more successful effort was made; and a marked impression was produced by the pieces then shown. In 1872 the regular employment of female artists and assistants was commenced. The increasing experience in the use of stoneware colours and in methods of designing has resulted in the addition of stoneware pâte-sur-pâte, impasto on faience, a new body called silicon-ware, mosaic decorations, relief and chiné wares, and various other outgrowths of the original Doulton ware. In 1882 the art department was centralised in a new building specially arranged with all conveniences for the needs of the work, upon which are now engaged about 200 female artists and assistants.

In December last, the Prince of Wales visited Lambeth Pottery for the purpose of presenting the Albert medal of the Society of Arts to Mr. Henry Doulton "in recognition of the impulse given by him to the production of artistic pottery in this country, and in view also of the other services rendered by Mr. Doulton to the cause of technical education, especially the technical education of women; to sanitary science by the productions of this firm; and, though in a less degree, to other branches of science, by the manufacture of appliances of suitable character."

MAXIM AUTOMATIC MACHINE-GUN WORKS.

This experimental laboratory was established by Mr. Hiram S. Maxim for the purpose of experimenting upon automatic guns, that is, guns in which all the functions of loading and firing are performed automatically by the action of the powder itself (Proceedings 1885, page 167). An automatic gun, which fires ten shots per second out of a single barrel by the action of its own recoil is shown at the works.

LONDON HYDRAULIC POWER COMPANY.

This company, incorporated by act of parliament in 1871 and extended in 1884, was established for supplying hydraulic power from high-pressure street-mains. The pressure employed is 700 lbs. per square inch. About 20 miles of mains have been laid in the city of London, in Westminster, and in Southwark; the whole are kept constantly charged by the machinery at the central pumping station, Falcon Wharf, Holland Street, Blackfriars. The works have now been in operation for about three years, and with great success. The number of hydraulic machines at present worked from the mains is about four hundred; and 1,350,000 gallons of water at 700 lbs. pressure are being pumped into the mains weekly. The power is charged for on a sliding scale per thousand gallons. The water after use in the machines is passed through a meter, and is then allowed to run into the drains. The whole of the works have been carried out under the supervision of the company's engineers, Messrs. Ellington and Woodall. The pumping engines and accumulators were made by the Hydraulic Engineering Co. at Chester; and the filtering apparatus has been constructed by the Pulsometer Engineering Co. The power supplied has been employed for a great variety of purposes, including the driving of general machinery with hydraulic engines; but the principal use has been for lifting, and for other machinery acting intermittently.

The chief points of interest in the installation at the central pumping station at Falcon Wharf are as follows. There are four sets of pumping engines constructed on Ellington's system; they are vertical triple direct-acting compound surface-condensing engines;

each has one high-pressure cylinder of 19 inches diameter, and two low-pressure cylinders of 25 inches diameter, with three plunger-pumps of 5 inches diameter, the stroke being 2 feet. The cranks are set at angles of 120 degrees with one another, securing a well-balanced engine with the advantages of three-throw pumps. Each engine is intended to pump into the accumulators 260 gallons per minute; under trial 296 gallons per minute were delivered with 205 indicated horse-power, the consumption of feed water being 20 lbs. per I. H. P. per hour.

Steam at a pressure of 85 lbs. per square inch is supplied by steel Lancashire boilers, each 7 feet diameter and 28 feet long. They are fitted with Vicars' mechanical stokers having self-feeding hoppers; and a Green's economiser is placed between the boilers and the chimney. Both stokers and economiser, as well as a lathe for small repairs, are driven by a small Brotherhood three-cylinder hydraulic engine bolted to the boiler-house wall.

The accumulators are two in number, 20 inches diameter and 23 feet stroke, and are loaded to a pressure of 750 lbs. per square inch. The connections are so arranged that either engine can be worked with either accumulator, and the water pumped can be delivered into any or all of the four 6-inch mains which radiate from the pumping station.

The water used is taken from the river through suction pipes laid below the foreshore to low-water mark; and is pumped into tanks over the engine-house, capable of containing about 200,000 gallons, and divided into several compartments for convenience of cleaning &c. The water is pumped either by pulsometers, or by centrifugal pumps driven by Brotherhood three-cylinder steam engines. After having been allowed to settle in the tanks, the water is drawn off from the top through floating suction-pipes, and flows down by gravity through large mechanical filters placed in the engine-room; after passing through these and through a bed of animal charcoal it is stored in the filtered-water tanks, placed over the boiler, from which the pumping engines draw their supply.

There are four sets of filters, 5 feet diameter, each containing two layers of small sponge about one foot in thickness, which are

kept compressed under a total pressure of about 7 tons applied by a small hydraulic cylinder above the upper filter chamber. When the sponge becomes clogged with the impurities separated from the water, it is washed by allowing water from the tanks to flow through it to waste, the compressing diaphragms being alternately raised and lowered by the hydraulic cylinder, thus imitating the action of cleansing a sponge by hand in a basin. The eight filtering layers, any of which can be used independently of the rest, are together capable of cleansing about 400,000 gallons of water in 24 hours.

There is an auxiliary pumping station at 2 Philip Lane, Wood Street, Cheapside, containing two boilers of the locomotive type, a 40-HP. non-condensing pumping engine, an accumulator 18 inches diameter and 20 feet stroke, coal bunkers, tanks, &c., and a lift to the street level: all within an area of 29 feet by 15 feet. The whole of the machinery, except the upper part of the accumulator, is below the street level; and the upper portion of the building is let for business purposes.

At Kensington Court, not far from High Street Station, Kensington, is an installation of an entirely novel character. Every house on the estate is fitted with a hydraulic lift, instead of a back staircase; these lifts are all on Ellington's hydraulic balance system, and are arranged so that they can be worked safely without the necessity of employing a special attendant. The doors on the various floors and the valve-gear are arranged on an interlocking system, so that no door can be opened unless the lift cage is at rest opposite to it, and the lift cannot be moved unless all the doors are closed. The pumping station contains duplicate Cornish boilers and non-condensing pumping engines, tanks for storage of water, and two accumulators.

GREAT EASTERN RAILWAY WORKS, STRATFORD.

These works, which were opened in 1847, include locomotive, carriage, and wagon departments, and occupy an area of about 48 acres; 12 acres are covered by shops, and 36 are used for yard and siding purposes. The total number of hands employed at the

present time is 3,857, of whom 1,697 are in the locomotive, 843 in the carriage, 363 in the wagon, and 954 in the running department. All new rolling stock for the railway is now built here, the average output being one engine, two carriages, and twenty wagons per week; besides which the existing stock of 685 engines, 3,080 carriages, and 14,300 wagons, is kept in repair mainly at these works. About 600 of the carriages are lit with compressed gas, the manufacture of which is carried on at the works.

LONDON CHATHAM AND DOVER RAILWAY, LONGHEDGE LOCOMOTIVE WORKS, BATTERSEA.

These works were designed about twenty-five years ago, and were opened in 1862 for the repair of the company's engines and rolling stock. The general plan of the workshops consists of a number of separate buildings with intervening spaces, an arrangement necessarily requiring a good deal of ground. The boundary wall of the works encloses an area of about 18 acres, which however is not all covered, there being room still for further extensions. The shops are fairly convenient in their arrangement and relative positions, though not possessing the advantages of the more modern plan of connected workshops, which are now built in successive bays of one storey; besides being cheaper in first cost, the latter occupy less ground, and afford better facilities for turning out work, by reason of easier intercommunication between the different shops, the transport of material from one to the other being much reduced in consequence. The workshops are very substantially built of brick, with iron roofs; and evident care has been taken in working out the designs so that the buildings should possess some architectural as well as useful features; the exterior surfaces of the walls are well broken up by the buttresses and windows, with good effect, presenting altogether a much less bare and monotonous appearance than is usual in erections of the kind.

The locomotive shops are arranged in the following order, side by side, lying north and south, with considerable spaces between them:—boiler shop; copper-smiths' shop; erecting shop; and smiths'

shop, which contains also the forge and springmakers' shop. Facing the north end of these shops, and lying east and west, are the fitting and machine-shop, brass finishing shop, pattern shop, wheel and heavy-tool and grinding shop, engine house and boiler, and range of offices. These are all contained in a long two-storied building; and the space between this building and the ends of the other shops forms the yard, down which run three lines of rails, having turntables opposite the different shops. The wheel yard and tiring shed are between the erecting and smiths' shop, and immediately facing the wheel shop.

The carriage shops abut on the end of the two-storied building, the principal shop being placed next to and parallel with the smiths' shop. The wagon shop, a recent addition of considerable size, lies immediately behind the carriage shop and in the same line, both being served by the same steam traveller. The roads in these shops are at right angles to the length of the buildings. The saw mill, which has recently been considerably enlarged and contains some of the most modern wood-working machinery, is conveniently placed at one side of the carriage shop, the ends abutting on the timber yard and drying sheds.

The following are the areas of the buildings:—

Boiler shop	980 sq. yards
Erecting shop	4,726 ,,
Smiths' shop	1,887 ,,
Fitting and Machine shop	1,397 ,,
Wheel shop	1,397 ,,
Carriage shop	4,972 ,,
Wagon shop	5,367 ,,
Saw mill	1,100 ,,

The work carried out consists principally in the repair and renewal of locomotive engines and tenders. In the carriage and wagon shops have been constructed the whole of the carriages and a large proportion of wagons which have been added to the stock for many years past. The total number of men employed is 668. The iron and brass foundry is at Dover.

Immediately outside the works is a running shed, planned by the present locomotive superintendent, Mr. William Kirtley, and

erected in 1877 to replace an old and inconvenient round shed, which had become too small for the increased stock of engines. The area of the new shed is 5,906 square yards, and it will hold ninety engines. In connection with the shed is a high-level coal-stage conveniently arranged.

BROAD STREET GOODS STATION.

At this goods station of the London and North Western Railway may be seen hydraulic machinery used in the performance of work connected with the receipt and despatch of merchandise. It comprises hydraulic lifts for trucks and other purposes, hydraulic capstans, and the engine and boiler house.

WHITECROSS STREET GOODS STATION.

This is one of the city warehouses for the receipt and delivery of goods carried by the Midland Railway. The machinery is worked by hydraulic power; and the engines, boilers, hoists, cranes, &c., employed to do the work, are as follows.

There are two pairs of horizontal direct-acting hydraulic pumping engines; one pair has 18-inch cylinders with 30 inches stroke, and the other pair has 16-inch cylinders with 22 inches stroke. Three boilers of the locomotive type: cylindrical part 10 feet 6 inches long, and 4 feet 4 inches diameter; fire-box shell 5 feet 6 inches long. Each boiler has 150 tubes of 2 inches diameter, with a heating surface of 853 square feet; heating surface of fire-box 94 square feet; total heating surface 947 square feet. Fire-grate area 18 square feet. Steam pressure 100 lbs. per square inch.

Two hydraulic accumulators: one has a ram 24 inches diameter and 20 feet stroke; the other has a ram 18 inches diameter and 20 feet stroke; water pressure 720 lbs. per square inch.

Nine hydraulic platform-cranes, of which two lift 50 cwts. each, five lift 25 cwts. each, and two lift 20 cwts. each. Two hydraulic wagon-hoists, each lifting 20 tons; three cage-hoists, each lifting 20 cwts.; six jigger hoists, each lifting 30 cwts.; total number of hoists, eleven. Fifteen hydraulic capstans, each having a hauling power of one ton.

Five wagon-traversers, of which two are worked by hydraulic cylinders, and the other three by the capstans.

The pressure main from the engine-house to the warehouse is 6 inches internal diameter. The exhaust water from the machines is returned to a tank in the engine-house to be used over again.

NATIONAL AGRICULTURAL HALL, KENSINGTON.

This Hall is being erected for agricultural and other exhibitions, similar to those held at the Islington Agricultural Hall. It is situated close to Addison Road Station of the Metropolitan Railway, and occupies 11½ acres. The main portion of the building is a great hall, 440 feet long by 250 feet wide, the Islington hall being 384 feet by 217 feet. It is covered by a semicircular arched roof, now in course of construction from the designs of Mr. Max am Ende and Mr. A. T. Walmisley. The roof is 374 feet long by 170 feet clear span, and is surrounded by a gallery 40 feet wide and about 20 feet above the ground; the clear height to the crown of the roof is about 100 feet. The style of construction has been adapted to the material employed, which consists of rolled iron bars; the various parts accordingly have strongly developed outlines, while the elementary bars are slender. The characteristic feature of iron structures of this class is the lattice bracing; and in this building the grouping together of systems of lattice bracing strictly in accordance with the requirements of strength is perhaps the most prominent feature, with which is connected an unusual economy of material. The way in which the horizontal thrust of the arches and the horizontal action of the wind are dealt with is of particular interest. At the top of the roof over the side gallery the foot of the semicircular arched rib is divided into two, one part going down vertically, and the other following the slant of the lean-to roof over the gallery, and then developing into a braced frame of 14 feet effective depth; in this form it continues vertically, and then horizontally underground to join the vertical branch. The traffic on the gallery floor and on the ground floor beneath passes through the loop formed by the two branches, in a manner most

favourable to economy of valuable floor space. The inner part of the loop is formed by a cast-iron column, which has a ball-pivot at each end and supports a portion of the gallery floor as well as the greater portion of the weight of the roof. Continuous and independent girders are used in the floor and in the roof, according to considerations of economy. Another point of detail is the simultaneous application in the semicircular roof of radial and tangential purlins. A novel construction is applied to the screens, consisting of very light lattice girders 4 feet deep, which are suspended vertically, and joined together not in one plane but in corrugations or zigzags. The covering, being glass and zinc as on the roof, follows the corrugations.

ANGLO-AMERICAN BRUSH ELECTRIC-LIGHT WORKS.

In the fitting and erecting shop may be seen Brush and Victoria dynamo armature-cores, old and new and in process of construction; core-winding machines, old and new; details of Brush and Victoria dynamo commutators; erection of dynamos; and tools generally for fitting and erecting. In the dynamo shed are machines in motion, including a Brush dynamo with automatic regulator for lighting the shops and the testing circuit, and other dynamos supplying current for manufacturing operations. The winding shop contains armatures and field magnets in course of winding. In the lamp-fitting shop are search lamps, small and large and automatic; Brush and Brush-Sellon arc-lamps; worm-wheel cutting and emery-grinding machines; a capstan-head lathe, and press tools. The testing room contains a 20-inch projector, Brush and Victoria dynamos of different sizes, Brush automatic regulators, Brush lamps on testing racks, Brush focussing or head-light lamps in an apparatus showing an image of the electric arc magnified about a hundred times, safety cut-out for multiple-series or group lighting, potential alarms, Victoria dynamos working projectors, dynamo driving a centrifugal fan, Wimshurst machines, and transmission dynamometers.

NORTH LONDON IRON WORKS.

At these works, belonging to Messrs. David Hart and Co., the manufacture of weighing machines without loose weights, a system introduced by this firm, is carried on. A new form of mechanical stoker manufactured here may be seen at work; it is designed for using ordinary small coal, which is fed into the furnace and distributed over it by a small jet of steam.

FOUNDLING HOSPITAL, NEW SANITARY WORKS.

The royal charter of the Foundling Hospital was obtained in 1739. In 1741 the present site was purchased, consisting of fifty-six acres in Lamb's Conduit Fields; and the western wing was ready for occupation in 1745. The chapel was built in 1747, the organ having been presented by Handel, who added £7000 to the charity by the performances of the "Messiah" alone. The picture gallery was inaugurated by Hogarth, some of whose most celebrated canvasses still adorn the walls. The exhibition of these and other works of art during the reign of George II. was the origin of the present Royal Academy. The hospital provides accommodation for 350 children of both sexes, the boys occupying the west wing and the girls the east.

The new drainage works were commenced in the beginning of the present year, and have just been completed, under the direction of Mr. W. D. Scott-Moncrieff. The sewerage is carried for the most part in cast-iron pipes through the old sewers, which at some points are as much as 7 feet in height. By means of manholes the drains are open to inspection throughout their entire length. The whole system affords an interesting and in several respects a novel example of modern domestic sanitation, carried out upon an extensive scale.

INDUSTRIAL DWELLINGS.

The Improved Industrial Dwellings Company was founded in 1863 by the present chairman, Sir Sydney H. Waterlow, Bart., and is the largest undertaking of its kind in existence. The buildings are erected in every quarter of London, and at present accommodate about 25,000 persons on 38 estates. The total expenditure on land and buildings to 30th June 1886 was £940,900; and the rent roll is about £100,000

a year. Additional buildings are in course of erection at a cost of nearly £100,000. Each dwelling is self-contained, that is, it possesses complete domestic conveniences for each family, and is wholly separated by party walls from the adjoining dwelling, nothing being used in common except the staircases, roofs, and playgrounds. Little or nothing has been attempted in the way of architectural effects, or in the provision of special mechanical appliances, the primary object being to provide at a moderate cost substantial homes of a comfortable and healthy character, and such as are suitable for the class for whom they are intended. The latest examples are to be seen at Miles Buildings, for 211 families, in Bell Street and Linton Street, Edgware Road; and at Sandringham Buildings, for 259 families, in the new street now being formed between Charing Cross and Oxford Street. As earlier examples worth inspecting may be mentioned Lumley Buildings, for 124 families, in Pimlico Road; Coleshill Buildings, for 122 families, in Ebury Street and Pimlico Road; Ebury Buildings, for 135 families, in Ebury Square; and Coburg Buildings, for 108 families, in Coburg Row at the back of Rochester Row, Westminster.

ELECTRIC LIGHTING INSTALLATIONS, COLONIAL AND INDIAN EXHIBITION.

Garden Illuminations.—These are supplied by Messrs. W. and J. Galloway and Sons, Manchester. About 10,000 incandescent lamps of 5, 10, and 16 candle-power are used; the current for them is supplied by four large compound-wound dynamos of the four-pole type, made by Messrs. Elwell Parker and Co., Wolverhampton, and having a capacity of 50 units each. They are driven by a pair of Messrs. Galloway and Sons' horizontal compound engines, each capable of developing 200 indicated horse-power, constructed specially for running at a high speed, and driving the dynamos without a countershaft; steam is supplied by four Galloway boilers. There are also 18 arc-lamps of the Brush type on three high masts, driven from a Brush dynamo situated in the west quadrant. For the illumination of the fountains 12 hand arc-lamps are used, each

of about 8,000 candle-power, driven by a compound-wound Brush-Victoria dynamo machine.

Internal Lighting of the Galleries.—The motive power for this purpose, supplied by Messrs. Davey Paxman and Co., Colchester, consists of a range of twelve steel boilers of locomotive type, and eight engines, namely two high-pressure coupled engines and six compound engines, together capable of developing 1,200 indicated horse-power. There are distributed in the different buildings about 450 arc-lamps, supplied by the Anglo-American Brush Electric Light Corporation, by Messrs. R. E. Crompton and Co., and by the Pilsen-Joel Electric Light Co.; they are fed by twenty-nine dynamos, of which twenty-three are in use, the remainder being held in readiness as spare machines. In addition to the arc-lamps, about two thousand 16 candle-power incandescent lamps are used for lighting the railway subway, Indian palace, refreshment rooms, and various offices. The current for these lamps is generated by six Edison-Hopkinson dynamos, supplied by the Edison-Swan Electric Light Co. Two batteries of accumulators, manufactured by the Electrical Power Storage Co., each capable of maintaining 400 lamps, are used in connection with some parts of this installation; one of these batteries is fed by an Edison-Hopkinson dynamo, and the second by an Elwell-Parker dynamo.

QUEENSLAND GOLD QUARTZ MILL, COLONIAL AND INDIAN EXHIBITION.

The gold quartz crushing machinery, erected on the south promenade by Mr. J. N. Longden for the Queensland commissioners, is a full-size working gold mill, in which are shown the whole of the processes from the crushing of the rough quartz to the production of the solid bar of gold. It consists of a battery of five stamp-heads, specially manufactured by Messrs. John Walker and Co., of Maryborough, Queensland. Each stamp-head weighs 800 lbs., and has a drop of 9 inches, and strikes 80 blows per minute. The stream of water supplied to the mill is 500 gallons per hour. The ore to be crushed, having first been broken into small

pieces, is fed into the battery from a hopper. From under the stamps the finely crushed stuff is carried by the stream of water through gratings of 240 holes per square inch, and flows over a series of mercurialised copper plates, through two centre-board wells, and over four ripples. From the tables it is carried by the water over a concentrator of the percussion kind. The concentrated pyrites are fed into a Boss grinding-pan, and delivered thence into two Berdan grinding and amalgamating pans, from which the pulp enters a 7-ft. settling pan as the last stage of the operation. Mercury is used throughout the whole process as the amalgamating agent; and for quickening its action and preventing it from flouring, sodium is employed at regular intervals, on the plan of Professor Crookes, F.R.S.

In Queensland the gold quartz mills run continuously day and night during the six working days of the week, or a total of 144 hours per week. The working power of the five-head mill exhibited is half-a-ton of quartz per hour; its weekly work would therefore be 72 tons. The mills are generally washed up once a fortnight, the whole of the amalgam being collected from each of the pans; this is cleaned and placed in a retort, where the mercury is distilled, leaving the gold in the bottom of the retort in the form of a cake, known as retorted gold, which is afterwards broken up, put into a crucible, and smelted into bars of gold for sale to the banks. The distilled mercury from the retort is used over again continuously in the mill. A real cake of retorted gold, being a fortnight's produce from a mine at Charters Towers, Queensland, is shown in the Queensland court of the Exhibition; its weight is 1,707 ounces, and its value £5,923.

ROYAL SMALL-ARMS FACTORY, ENFIELD.

The arms manufactured at the Royal Small-Arms Factory comprise the Martini-Henry rifle; the triangular bayonet; Enfield breech-loading revolver; Martini-Henry carbines, cavalry pattern and artillery pattern; sword-bayonets of various patterns; lances;

leather scabbards for triangular and sword bayonets; new Enfield Martini rifle and carbine; new-pattern cavalry sword; and rifle-calibre machine-guns.

Martini-Henry Rifle.

The rifle consists of a barrel screwed into a shoe or body, a butt, and a fore-end. The body contains the breech action, which is the mechanism for closing the breech, firing the cartridge, and extracting the empty cartridge-case.

The breech is closed by a block which swings on a pin passing through the upper rear end of the shoe or body, the recoil being taken by the shoe. The cartridge is exploded by the striker, a direct-acting piston, which is driven by the action of a strong spiral spring within the breech block. A lever in rear of the trigger-guard acts on the breech block, so that the action of pushing the lever forward causes the block to fall, the tumbler to be carried round until the trigger-nose drops into the tumbler-bent, the main spring to be compressed by this motion as the crane of the tumbler draws back the striker round which the spiral spring is coiled, and the empty cartridge-case to be thrown out to the rear. On drawing back the lever, the block is raised so as to close the breech, and the arm is ready to be fired.

The stock is made from Italian walnut, and is in two parts, the butt and the fore-end. The butt is secured in the socket of the shoe or body by means of a screw bolt; and a loop and pin, and two bands, connect the fore-end to the barrel. In the latest pattern rifle the loop and pin have been replaced by a fore-end hook, which engages into a recess in the front of the body.

The length of the rifle with bayonet fixed is 5 feet $11\frac{1}{2}$ inches; and without bayonet, 4 feet $1\frac{1}{2}$ inches. Its weight without bayonet is $8\frac{3}{4}$ lbs.

Stock.—The Italian walnut, of which the butt and fore-end composing the stock are made, is found well suited for the purpose, owing to its lightness, hardness, and closeness of grain. The rough butts and fore-ends, obtained by contract, are examined on arrival, and should any of the following defects be observed, they are rejected:—

under size; crooked, at fore-end only; galls, the result of wound in tree; shakes or cracks; rind galls, the result of injury to bark of tree when young; discoloured wood; bines or knots; cross grain; bad quality; perished wood; fly and worm holes; impregnation with salt water. All except the last of these defects are readily detected by the examiners; and should the appearance of the wood lead them to suppose that it has been damaged by salt water, a shaving is taken off with a spoke-shave, and is dipped in a solution of nitrate of silver (1 grain in 1 ounce of distilled water), when, should any salt be present in the wood, a white precipitate is formed of chloride of silver. If wood which has been damaged by salt water be used for a stock, it will rust any steel or iron with which it comes in contact; and no method is known by which to remove the salt from wood that has once been damaged.

The butts and fore-ends are usually in a half-seasoned condition when received, and are stacked to season in the stock stores. Green wood requires about three years to season. If it is necessary to hasten the seasoning of the wood, the rough butts and fore-ends are placed in the desiccating room, and subjected to a heat of 60°, gradually increasing to 90° or 100° Fahr. If half dry when placed in the desiccating room, they will be ready for use in about six or seven weeks.

Butt.—The principal machine operations in the manufacture of the butt are as follows:—boring for stock bolt; rough turning; sawing to length; bedding the butt-plate; finished turning; bedding for shoe, and for lever catch-block; counter-sinking and facing for body; hand-finishing.

Fore-end.—The principal machine operations are:—rough turning; grooving for barrel; sawing to length; fitting the nose-cap; finished turning; bedding for body, rod-holder, and fore-end hook; boring for rod; hand-finishing.

Barrel.—The barrel is made of soft or mild steel prepared by the Siemens-Martin process, this metal having been found to be of a very uniform quality. The barrel bars or moulds are obtained by contract in lengths of 15 inches, the diameter for rifle bars being $1\frac{1}{2}$ inch.

Forging.—The barrel bar is heated to a white heat, and passed through the barrel rolling-mill, which consists of ten pairs of rolls arranged alternately horizontally and vertically, whereby it is drawn out in one heat to the full length required of about 36 inches, taper in form, and solid. It is next passed to the Ryder forging machine, where the "Knox form" is forged on the breech end, and the barrel cut to length. It is then passed through a straightening machine, examined for straightness, and viewed as finished-forged.

Barrel Machine-Room. — The machine-operations consist in clamp-milling for size and length the ends of the barrel; and then drilling up each end about $\frac{1}{4}$ inch, the diameter of the holes drilled being 0·41 inch. This operation is called "entering the bore"; occasionally a barrel is drilled $1\frac{1}{2}$ inches up at each end, and is very carefully tested to see that the starting of the bore is true and correct. The barrels are then ready for drilling.

Drilling.—The barrels while being drilled are placed horizontally, three in a machine, where they revolve at 940 revolutions per minute, the holes already made acting as guides for the half-round or D bits used at each end in the operation. Underneath the bits is placed a brass lubricating tube of $\frac{1}{8}$ inch diameter, through which pure soap is forced at a pressure of 60 to 70 lbs. per square inch; this forces the cuttings or "swarf" out at each end of the barrel. The brass tube is made to oscillate by means of a cam on the shaft connected with the driving pulleys; the same shaft also works the feed slides at each end of the machine. The traverse of the slides is $\frac{1}{2}$ inch per minute. The bits are run in about 6 inches from both ends; the slides are then drawn back, and the bits pushed to the bottom of the hole, ready to drill another 6 inches length; and so on until they meet at the centre, where as a rule they do not deviate more than from 0·005 to 0·008 inch. The drilling occupies from 35 to 40 minutes. After the barrel has been drilled, the hole is enlarged 0·02 inch in diameter by means of a three-toothed draw-bit; this operation occupies 3 or 4 minutes.

The hole is now broached out with long square bits, on one side of which a strip of oak is placed. Long strips of writing paper are evenly placed between the strip and bit, one upon another, and the

bit is run through the barrel until the hole is broached out to the required diameter. This operation is more of a burnishing than of a cutting character, producing a fine, clear, polished surface, down which a shadow is readily thrown by holding the barrel at the proper angle to the light. As shadows thrown off straight surfaces are projected in straight lines on any true surface on which they are thrown, the practised eye can detect any inaccuracy in the bore of a barrel by the appearance of the edges of the shadow thrown down it. In order to ensure absolute certainty that no barrel which has not the bore perfectly true shall be passed on for the exterior to be turned, the following mechanical test has been devised:—a steel rod is stretched taut between two horizontally fixed headstocks, having a collar in the centre and at one end, which fit the bore loosely, so that the barrel can freely revolve on the rod. If the bore is straight, the end of the barrel where there is no collar on the rod will run perfectly true; but, if not straight, it will revolve eccentrically, and its motion is easily detected even by an unskilled person. Every barrel is passed through this test before the turning of the exterior is commenced. The bore is also tested for size by the collars on the rod.

Turning.—The next operation is to support and hold the bore true, while the outside is turned perfectly concentric with it. After a number of experiments to find out a means of fixing a true turned bush or collar on a rough exterior, the present method of running sulphur in a liquid state between the barrel and bush was adopted. By this means the exterior of the barrel can be turned perfectly true with the bore, without injury to the inside. The barrel being placed vertically, two plugs, whose centres coincide with the axis of the barrel, are placed in the breech and muzzle; the bush is then held over it, and melted sulphur is poured in between barrel and bush. This gives a bearing for the outside perfectly true with the bore. The barrel is now rough-turned, finish-turned, draw-polished, gauged, chambered for proof, and a screw-thread is cut in the breech end, to take the "hutts" which are used for closing the breech during the first proof. This system of turning a barrel enables its exterior to be brought to a definite size, and is greatly superior to the old method of grinding barrels on a large stone, and afterwards striking them up.

First Proof.—The barrels now undergo the first proof test, which is necessary in order to detect inferior quality of metal, and flaws that do not appear on either the exterior or interior surfaces. The first proof charge is $7\frac{1}{2}$ drams of powder, a lead plug of 715 grains, and over the latter a cork wad $\frac{1}{2}$ inch thick. Twenty barrels are proved at the same time in a cast-iron proof battery.

Finished Milled.—The seat for the front sight is next cross-milled and dovetailed, and the steel for the front sight is sawn to length and brazed on. The barrel is then finished-bored, and set, and is now ready for rifling.

Rifling.—The rifling is done with a cutter having a head of suitable form for the rifling required. This is fitted into a groove cut in a box about 8 inches long, and fitting the bore. It is drawn through the barrel by a rod fastened to one end of the cutter-box, the other end of the rod being coupled into the spindle of the headstock or traversing saddle. On the spindle is a pinion geared into a sliding rack carried by the same saddle. The end of the rack is fitted to slide backwards and forwards along a fixed bar, which can be set at any angle necessary to rotate the spindle and cutter-box to the amount of spiral required. From four to five cuts are needed for each groove; and the cutter is fed up by a screw tapped into the end of the cutter-box, to which is attached a rod working through the centre boss of a hand-wheel. A spiral groove is cut along this rod, in which slides a feather fixed in the boss of the hand-wheel, enabling the feed-screw to be screwed in or out by the hand-wheel as required. An index is connected with the hand-wheel, enabling the operator to read off the depth of cut. The barrel is fixed in a rotating chuck, which is divided so that any number of grooves required can be cut inside the bore. The rifling is of a uniform twist of 1 turn in 22 inches, or $1\frac{1}{2}$ turns in the 33 inches length of bore. The form of rifling is that known as the "Henry" rifling; the grooves are seven in number, and are 0·007 inch in depth.

Screwing and Chambering.—The barrel is suspended inside a hollow rotating spindle by a plug inside the muzzle end, running on a plug fixed in the headstock at the breech end. A guide-screw is

securely fixed on the rotating spindle, and carries a nut fixed to a traversing tool-holder, which holds a peculiar form of chasing tool. The teeth for cutting the screw-thread on the breech end are on the under side, so that, being set over the top of the rotating barrel, the tool can be lifted in and out of the thread which is being cut, in the shortest possible time and distance, without chopping the thread. When the screw is finished, the barrel is driven from it, while the breech end is chambered up for the cartridge. This is an ordinary operation of boring and reamering in a lathe.

Second Proof.—The barrel is next breeched up to body, the action put together for proof, and the rifle undergoes the second proof test. The second proof charge consists of 5 drams of powder, and a bullet weighing 715 grains. The barrels are proved in a proof battery somewhat similar to that used for the first proof.

Sighting.—The back sight-bed is soldered on to the barrel, and also secured in its place by two screws. Both the back sight and front sight are adjusted and regulated from the axis of the bore; and when viewing the barrels for sighting, the greatest care is taken to see that both sights are exactly in position.

Browning.—The body and barrel are browned separately. The following is the browning mixture at present in use:—spirits of wine 5 ounces, spirits of nitre 8 ounces, tincture of steel 8 ounces, nitric acid 4 ounces, sulphuric acid 3 ounces, blue vitriol 4 ounces, water 1 gallon. The barrels and bodies are first scalded in a solution of soda for twenty minutes, and are then washed in clean water. The browning mixture is applied, and they are placed in a damp heat for about an hour and a half; after which they are scalded again, and when cool the rust is scratched off. This process is repeated four times, and then the barrels are cleaned off and oiled. The whole operation of browning takes about eight hours.

Body.—The body is made from a specially tough class of mild steel. Bars of this metal, 4 or 5 feet in length, and 2 inches by $1\frac{1}{2}$ inch in section, are obtained by contract.

Forging.—The body is blocked direct off the end of the bar by five blows under a 15-cwt. steam-hammer. The first blow gives a rough figure, and measures off the quantity of metal required. The

second blow fullers in the sides of the body, to displace the metal when working the hole through it. The third blow, by means of a chisel in the upper die, splits the metal in the centre, driving out the sides of the body to fill the die, and leaving the impression of the hole, to be made through the body, full size at top. By the fourth blow a full-sized drift, placed in the hole just made by the chisel, is driven clean through, shearing down the sides, and driving through the small piece left at the bottom of the hole. The hole made through the body is now 3 inches by $\frac{7}{8}$ inch by $2\frac{3}{4}$ inches; and the weight of metal wasted is only $3\frac{1}{2}$ ounces. The fifth blow cuts the body off the bar. A mandril is then driven in the hole, and a blow is struck upon the ends to square them up, and the body is now ready for stamping.

Stamping.—The body is reheated, and a cold steel mandril driven into it; and it is then placed under a powerful steam-hammer. On the anvil of this hammer is the lower die of a pair, and the impression cut in the pair of dies is that of the finished size of the forged body. One heavy sudden blow is given, with force sufficient to make the metal flow into every corner of the impression. If this is not done at the first blow, it cannot with safety be attempted by a second blow without reheating; for the surplus metal which flows over between the faces of the dies in the form of a thin fin, chilled and black, would itself absorb the force of a second blow, and perhaps split one of the dies. The body is next annealed, the scale pickled off, fin trimmed, and passed as "finished forged."

Machine Operations.—The hole in the body is first drifted out by means of long drifts slightly tapered, which are drawn through it; and the hole thus produced is used as a starting-point for all the subsequent operations. After drifting, four bodies are placed on a revolving cross-shaped fixing, the arms of which exactly fit the holes in the bodies, while a transverse slide carrying two tool-holders, one on each side, turns up both sides of the four bodies at one operation. This operation leaves the sides of the body equal in thickness, and true with the centre hole. Twelve bodies are next fixed on a revolving head, and the barrel ends are all cut square and true, the stock ends being treated in the same manner. The hole for the

barrel is then drilled and tapped; and the burr thrown up by tapping is smoothed down. The face is eased, so that when a gauge is screwed in, it stands exactly true. The body is now placed in a drilling jeg, and the adjusted face is screwed tight up against a rib in the jeg, while the six axis holes of various sizes are drilled, three in each side. The drills run through hardened steel bushes fixed in the sides of the drilling jeg. These axis holes, after being tested for accuracy, become, in conjunction with the large hole in the body, the base points for the remaining operations.

A number of drilling machines now operate to cut away the metal, so as to form the socket to receive the stock butt. The hole is drilled and tapped to receive the screw end of the stock bolt, which secures the butt in the socket. Pins in the axis holes in the left side of the body hold it while the knuckle seat for the breech block is roughly cut out, and the seat milled out square and true. A number of minor milling, drilling, and tapping operations bring the body into the shape and figure required; and it is then screwed on, or "breeched up," to the barrel. The barrel is now placed vertically with the end of the chamber resting on the collar of a plug, which enters and exactly fits the chamber; and the face of the barrel is drawn tight down on this collar by means of plugs pushed through axis holes in the body. Small mills are now run on a spindle through the block axis-hole, and finish cutting out the knuckle seat of the block to a positive length from the face of the barrel. This length between the knuckle seat of the block and the face of the barrel is rigidly maintained, so as to ensure that the block will interchange or fit in any body; for this purpose each breeched-up barrel and body is accurately gauged with hardened steel gauge-blocks. Care is also taken to see that the striker hole, in the face of the gauge-block, coincides with the axis of the bore of the barrel, so as to ensure the cap of the cartridge being struck in the centre. The barrel and body are now passed on for putting together the action for second proof.

Emery Wheels.—A particular form of emery wheel, called a "rim wheel," has been introduced for finishing up some of the components. Its use has enabled unskilled labour to take the place of a high class

of skilled workmen, and the work is better finished. For instance, the slot of the back-sight leaf is first drifted to its true size. By this it is held in a fixing attached to a vertical axis, and both edges with cap attached can be passed across the face of the rim wheels, maintaining it perfectly true, and grinding the edges of the leaf and cap parallel to each other. The sides are done in the same manner.

The method pursued in the manufacture of all the other components is precisely that followed in the case of the body. All the parts are first of all forged in dies, the fin is trimmed off, they are pickled to remove scale, and they then undergo numerous milling, drilling, and other machine operations, until they are brought to the correct figure, when they are viewed, gauged, and either case-hardened, browned, blued, hardened, or tempered, &c., as the case may be.

The barrels of carbines and pistols are treated in the same manner as the rifle barrel. In order to ensure an absolute interchangeability of the various parts, the most exact system of gauging is a necessity; and the strict examination which is enforced prevents the possibility of any defective parts being put into an arm.

The following list gives the nomenclature of the remaining parts of the rifle, and the materials of which they are made. Wrought-iron:—lower band, upper band, block, butt plate, fore-end hook, guard, lever, lever catch-block, nose-cap, nut for upper band, sight bed, sight cap, stock bolt, band swivel, guard swivel, washer for stock-bolt. Steel:—cleaning rod, extractor, front sight, indicator, rod-holder, sight leaf, sight slide, stop-nut, striker, trigger, tumbler. Wrought-iron screws:—two butt screws, guard-swivel screw, lower-band screw, nose-cap screw, two rod-holder screws, upper-band screw. Steel screws:—extractor-axis screw, two fore-end hook screws, indicator-keeper screw, sight-bed screw, sight-cap screw, sight-spring screw, stop-nut keeper screw, trigger screw, trigger-spring screw. Steel springs:—lever catch-block spring, main spring, sight spring, trigger spring. Steel pins:—block-axis pin, lever catch-block pin, lower-band pin, sight-axis pin, upper-band pin.

Case-Hardening.—The breech block, lever, butt plate, and iron screws, are case-hardened. This is done by carefully packing them in iron boxes, in which they are surrounded with bone cuttings or animal charcoal. An iron plate is laid on the top of the box, which is then placed in a furnace and raised to a red heat. The length of time that the various articles are left in the furnace depends on the amount of case-hardening required. When removed from the furnace they are chilled in a tank of cold water. They are then cleaned, oiled, and examined by gauges to ascertain whether the case-hardening has altered their form.

Tempering.—The following components are hardened by being raised to a certain temperature and then cooled in oil:—striker, main spring, indicator, extractor, sight spring, catch-block spring, trigger spring, block-axis pin, extractor axis, sight slide, and steel screws, &c. These are afterwards tempered by "blazing," that is by heating them again until the oil or suet with which they have been covered bursts into a flame.

The following components are blued:—upper and lower bands, upper and lower band pins, guard and band swivels, fore-end hook screws, sight leaf, lever catch-block and pin, guard, nose-cap, rod-holder, &c. These are polished, cleaned with lime to remove grease, and then covered with powdered charcoal and raised to a temperature of about 550° Fahr.

Triangular Bayonet.

The blade is made of tool or sharp steel, the socket of mild steel, the locking ring of wrought iron, and the locking-ring screw of steel. The blade and socket are welded together, the blade is tapered under a Ryder hammer, and then rolled out in segmental rolls to the required length and a triangular figure. The socket is stamped to size, and then goes through several machine operations, such as drilling, milling, slotting, &c. The blade is hardened and tempered, ground and polished; the socket is browned; the locking ring is blued, and its screw is case-hardened.

Enfield Breech-Loading Revolver.

This revolver differs from the patterns usually met with in having a rebounding lock, and in its method of extracting the empty cartridge-cases. The principal parts are the barrel, the cylinder, and the body. The barrel is $5\frac{7}{8}$ inches in length; the diameter of bore and the form and twist of the rifling are the same as in the rifle. The barrel is attached to the body by means of a screw passing through a knuckle-joint in an arm which projects below the breech end. It is held in the firing position by a spring catch in front of the hammer. The axis-pin of the cylinder is screwed into the body, its point resting in a recess in the joint-arm of the barrel; a projection or boss on the cylinder engages in the same recess. By this arrangement, when the catch holding the top bar is released and the barrel depressed, the cylinder is drawn along its axis; and the bases of the cartridges in the chambers being held by a radial extractor, which is free to move only a short distance along the axis-pin, the cartridge cases are drawn from the chambers to such a distance, that those which are empty are free to fall away, while filled cartridges are held by the bullets remaining in the chambers. The cylinder contains six chambers, and the pistol is loaded in the ordinary way.

The lock action consists of seven components:—hammer, axis screw, trigger, trigger-axis screw, pawl, lever, and mainspring. The mainspring governs the movement of each component. The act of pulling the trigger cocks the pistol and fires it, and upon the release of the trigger the hammer rebounds to half cock. The stock is of walnut, and the remaining parts are of steel. The system of manufacture is similar to that of the rifle. The weight of the pistol is 2 lbs. $8\frac{1}{2}$ oz.

Martini-Henry Carbines.

The carbines of the cavalry and artillery patterns have the same calibre as the Martini-Henry rifle, namely 0·45 inch, and have also the same twist and form of rifling, but the barrels are only 19 inches in length. The processes of manufacturing the various parts are

precisely the same as those for the rifle. The length is 3 feet $1\frac{11}{16}$ inches. The weight of the cavalry carbine is 7 lbs. 8 oz., and of the artillery carbine 7 lbs. $10\frac{1}{2}$ oz.

ROYAL ARSENAL, WOOLWICH.

The following is a list of the principal operations carried on at the Arsenal.

Royal Laboratory.

Main Factory.—Manufacture of small-arm bullets &c.; squirting rod-lead for ditto. Rockets, war and life-saving. Submarine mines. Metal powder-cases. Zinc cylinders. Metal fuzes of various sorts. Tubes, brass vent-sealing.

Model Room.—Patterns of the various stores manufactured.

Wood Department.—Cutting out and making boxes for small-arm ammunition, and various kinds of chests and boxes for war stores. Wood fuzes. Tent poles, and various parts of heads for detonators &c.

Cartridge Factory.—Casting and rolling metal strip. Operations connected with solid-drawn and rolled cartridge-cases. Making empty small-arm caps &c.

Shell Foundry.—Various operations in connection with moulding and casting projectiles.

Rifle-Shell Factory.—Turning and finishing projectiles. Lead-coating rifled breech-loading projectiles. Welding in bottoms on steel tubes to form shell. Forging and grinding Nordenfelt bullets.

Royal Carriage Department.

Carpenter's Shop.—Dove-tailing and tenoning machines.

Wheel Factory.—Wheel making.

Main Forges.—Stamping by hammer and by hydraulic press. Nut and bolt making.

Foundry.—Manufactures in malleable cast-iron and phosphor-bronze.

Turnery.—Lathes. Worm-wheel cutting. General engineering and other tools.

Main Machine-Shops.—Boring and planing torpedo-tubes. Turning torpedo-balls. Horizontal circular plane. Wall plane. A 4 ft. 6 in. slotting machine. Band-saw for cutting iron. General engineering tools.

Completed Articles.—In mounting ground and in pattern room.

Royal Gun Factory.

Forges.—Radcliffe steel furnace. Casting steel ingot. Forging at 40-ton and 12-ton and 6-ton hammers.

Turneries.—Turning guns from 68 tons to 2 tons. Milling outside of guns for locking joint. Boring and rifling heavy guns.

South Turneries.—Heavy boring machines. Electric light for examining interior of guns.

Sighting Room.—Fitting breech-action to guns. Sighting guns.

Gun-Boring Mill.—Boring and rifling guns. Trepanning ingots and forgings.

Testing Room.—Testing steel for guns by tension, and by flexion.

Field-Gun Section.—Lower shop: milling hood of gun, and milling breech-screws; turning trunnion-arms; turning and rifling field-guns. Upper shop: milling sight-bars, slides of locks, locks, hammers, automatic clamps.

Specimen Shop.—Preparing steel specimens for testing by tension and by flexion.

Obturating Shop.—Making obturating-pad. Pressing pads. Stamping graduations on aluminium strips for sights. Nickel-plating.

Engine Repairing Shop.—Turning, boring, and rifling guns. Testing steel wire, throughout the whole length with 65 tons per square inch; and testing 100 inches length to ascertain elongation and breaking weight.

Outside Shops.—Tempering steel tubes. Boiling steel tubes, hoops, &c. Shrinking hoops on guns.

Pattern Room.—Finished guns.

BECKTON GAS WORKS.

Beckton, or "Beck Town"—so called in honour of a former governor of the Gas Light and Coke Company, the late Mr. Simon Adams Beck—is situated in the Essex marshes at a point towards the lower end of Gallions reach of the River Thames, about ten miles east of London. The company's old works, lying almost in the heart of London, did not admit of extension; and when larger premises became necessary, it was considered that the cost of coal delivery might be greatly reduced if the works could be removed some distance lower down the river, so as to avoid the expense of barging and cartage; while at the same time, by having plenty of land, there would be ample space for the storage of such residuals as coke, tar, and ammoniacal liquor. The present site having been secured, the first pile of the new works was driven on 19th November 1868, at which time Beckton was an uninhabited marshy swamp; but such rapid progress was made that the works were put in operation on 25th November 1870; and so extensive have been the additions since that date that Beckton may now be described as a town in reality as well as in name.

The pier forming the approach to the works from the river is a wrought-iron structure supported on cast-iron cylinders, having a frontage parallel to the river of 800 feet, and projecting forwards 400 feet from the shore into the river. It affords berthing accommodation for five steam-colliers of the largest size; and for discharging their cargoes each berth is provided with three steam or hydraulic cranes and a movable steam-crane; the unloading power is fully equal to 12,000 tons in twenty-four hours. In addition to the pier there are two jetties, and ample quay accommodation for smaller craft.

On reaching the shore the pier joins a viaduct, on the same level and forming a continuation of it. At the point of junction four branches start from the main viaduct, two running along the right-hand side through a series of six retort-houses, and two along the left-hand side through a similar set of six retort-houses. The main viaduct, which has a double line of rails, runs along the whole

length of the space between the two sets of retort-houses, a distance of three-quarters of a mile from the river to the end.

The twelve retort-houses are all very much alike. The largest is 510 feet long by 100 feet wide, and is capable of producing 5½ million cubic feet of gas per day. Running through the house on either side are high and low-level railways of standard gauge; the high-level railway is used for conveying coals from the steamers alongside the pier to the coal stores within the house; the low-level railway is for taking away the coke drawn from the retorts. Locomotives and iron wagons are employed on these railways. In the largest house there are forty-five beds, each containing nine fire-clay retorts of 20 feet length, making a total of 405 retorts. Each retort-house has a complete set of purifying and other plant attached to it: so that the Beckton works may be said to be made up of twelve complete gas works, the smallest of which is of no mean calibre.

The coals are delivered into stores which are conveniently placed in the retort-house, so that the retorts may be readily charged from them. Each retort is charged with about 3 cwts. of coal every six hours. The mouthpieces of the retort are securely closed up with iron lids. The gas as it is distilled from the coal passes up through vertical pipes, fixed at each end of the retort, into a long wrought-iron vessel, rectangular in section, placed on the top of the retort beds, called a hydraulic main; its principal purpose is to serve as a self-acting valve for shutting off the gas when the mouthpieces are opened for charging and discharging the retorts; and it is also here that a large proportion of the tar is thrown down, and some ammoniacal liquor. When a charge is "burnt off," the lids are opened, and what remains, namely coke, is drawn out and deposited on the floor beneath the charging stage; a portion of the coke is used for keeping up the heat of the retorts, and the remainder is loaded up into wagons and taken away for sale.

The gas is withdrawn from the hydraulic mains by exhausters, and is next passed through a series of horizontal cast-iron pipes of 12 inches diameter, called condensers, around which the air is allowed to circulate freely. In this apparatus the tar and ammonia travelling

with the gas from the retort-house are condensed, and are run off into storage tanks.

The gas issuing from the condensers is still very foul; for although nearly all the tar is eliminated, it still contains a considerable quantity of ammonia, carbonic acid, and sulphuretted hydrogen. To absorb these it must be propelled through "washing" or "scrubbing" vessels. The scrubbers are generally in the form of circular towers, about 60 feet high, constructed of cast-iron plates, and filled with coke broken up to a convenient size; on the top is placed brushwood, to act as a distributor for the liquid. The foul gas entering at the bottom of the scrubbing tower and ascending through the coke is met by weak ammoniacal liquor or clean water percolating through the fine interstices of the brushwood, whereby the whole of the ammonia remaining in the gas is absorbed; and the combination is ammoniacal liquor, with which some carbonic acid and sulphuretted hydrogen are also taken up.

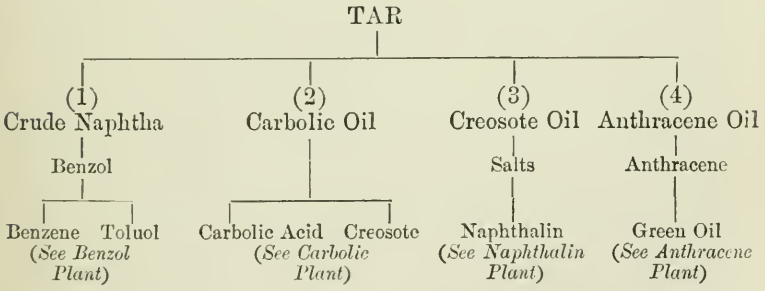
The gas has next to pass through eight purifying vessels in the following order:—first through two vessels containing clean carbonate of lime, which removes the whole of the carbonic acid left in the gas; next through two vessels containing oxide of iron, which cleanses it of sulphuretted hydrogen; thirdly through two vessels of lime that has been previously sulphuretted, which removes the greater part of the bi-sulphide of carbon; and finally through two more vessels charged with clean lime, by which all traces of sulphuretted hydrogen are eliminated.

The gas being now as pure as it is possible to make it, and of the required illuminating power, is in a fit state to be delivered for consumption; but before this is done, it is first measured through large station-meters, and stored in gas-holders from which it is pumped out as required. For this purpose there are eight gas-holders at Beckton, from which by means of eight large gas-exhausters on Beale's rotary plan, each capable of pumping 250,000 cubic feet per hour, the gas is propelled along two cast-iron mains of 48 inches diameter, from Beckton to Westminster, picking up from other stations on its way, and filling up other gas-holders along the line of route.

To give some idea of the magnitude of the gas manufacture at Beckton, it may be mentioned that the company have eleven manufacturing stations in all, situated in various parts of the metropolis and suburbs; and the quantity of coal carbonised annually is about $1\frac{3}{4}$ millions of tons, of which more than half is consumed at Beckton alone.

Products Works.

Tar Distillation.—Tar is a residue resulting from the manufacture of gas: to utilise it is the primary object of tar works. The initial step is distillation, under which the tar gives off its different oils, and leaves a sediment known as pitch; these are called the direct or immediate products. The oils possess many virtues; and the study and practical application of their several properties form the main manufacturing industry of the works. The following table shows the order in which the several products are evolved, and their further development and application towards finished products:—



Benzol Plant.—Crude naphtha from tar stills, received into crude stills, gives three qualities in distillation. These are chemically treated and again distilled, the result being crude benzol, which on further distillation gives pure benzol or benzene, and toluol. From these are obtained the aniline dyes.

Carbolic Plant.—Carbolic oil contains carbolic acid, which is obtained by treating the oil with a solution of soda, whereby the original oil is divided into creosote oil and carbolate of soda. The

latter when treated with sulphuric acid yields carbolic acid, so widely known as a disinfectant.

Naphthalin Plant. — Creosote oil at an ordinary temperature separates into two substances, one a solid known by the name of salts, and the other a liquid. Creosote oil possesses great preserving properties, and is largely used for pickling timber. The salts are received into hydraulic presses, for extracting the oil remaining in them. The pressed salts are distilled, and after being chemically treated are again distilled; the result is purified naphthalin, which while in a solvent condition is run into candle-shaped moulds, and in this form is known as albo-carbon, the substance used in the albo-carbon gas-burners. In its purest state it is used for colour manufacture.

Anthracene Plant.—Anthracene oil from tar stills, received into shallow tanks for cooling purposes, is then pumped through filter presses; the solid portion left in the presses is called anthracene, of which about 15 per cent. is pure. This placed under hydraulic pressure yields anthracene of which 35 per cent. is pure. Anthraquinone derived from pure anthracene is the foundation of alizarine colours. The oil left after the extraction of anthracene is called green oil, and is largely used for lubricating purposes.

Sulphate of Ammonia.—Ammoniacal or gas liquor, a residue of gas manufacture, contains ammonia, part of which, called free ammonia, is readily liberated by the simple application of heat. The other portion, or fixed ammonia, is evolved by the treatment of the gas liquor with lime. The mixture collected in a boiler is heated by steam, whereby the fixed ammonia is liberated in the form of gas, which is conveyed to a tank or saturator charged with sulphuric acid. The action of the acid on the ammonia results in the formation of a salt which precipitates; this when collected and thoroughly dried is the article known commercially as sulphate of ammonia, so widely used for agricultural purposes.

Sulphuric Acid. — Oxidised sulphur fumes condensed form sulphuric acid. The fumes are obtained by burning copper ore, spent oxide, or sulphur; the two former of these are utilised here. The fumes pass over a vessel containing nitrate of soda and sulphuric

acid, and generate nitre gas, which is the oxidising agent. The two gases are together conveyed upwards through a tower into large chambers supplied with jets of steam, which condense the sulphur fumes, thus forming sulphuric acid. The nitre gas after the formation of the acid is still available, and is utilised as follows :— on issuing from the chamber it is passed up through a tower, meeting a descending current of sulphuric acid, which now in its turn becomes an absorbing and oxidising agent. The mixture is conveyed and allowed to fall down the first tower previously mentioned, where it meets fresh fumes ascending on their way to the chamber. The process is thus repeated indefinitely.

ROYAL VICTORIA AND ALBERT DOCKS.

These together form one vast dock $2\frac{3}{4}$ miles in length. They are situated on a wide open reach of the Thames, at North Woolwich, within one hour's steaming of Gravesend. Entering from the east is observed the river wharf, stretching from this entrance in an E.N.E. direction for a distance of 1,120 feet down the river. The depth alongside is 27 feet at low water, so that the largest steamers can lie there at any time of tide to coal, take in cargo, and embark or disembark passengers. Railway lines are laid along this wharf for both passengers and goods, in connection with the general railway system of the country; and a customs and a railway station abut upon the wharf.

The Royal Albert Dock.—This dock was completed in 1880, with the exception of the new works, which were commenced in May 1884, and were finished on the 24th of April 1886, by a blasting operation on a gigantic scale. This consisted in the removal of the dock wall forming the north-east side of the Gallions basin, 520 feet long, 38 feet high, 5 feet broad at top, and 6 feet at base, the total weight being 7,850 tons. At either end of the wall, where it met the side walls of the basin, holes were perforated which extended from the rear of the wall to within a few inches of its

face, for the purpose of permitting the shattered material to detach itself from the side walls without injury to the latter. For the blasting were used 2,900 lbs. of gelatine dynamite, distributed in 1,430 holes, the charges varying from six pounds at the foot of the wall to half-a-pound at the top. The whole of the charges were fired by electricity simultaneously. With little or no noise, the entire mass was broken up into fragments of from about 5 tons to pieces of the size of road metal, and subsided into the water within a few feet of where the wall had stood. The calculations as to the quantities and distribution of the charges were made with such accuracy that the exact amount of work required to be done was accomplished, and no more.

This dock is entered from the Thames by two parallel and contiguous locks, each 550 feet long and 80 feet wide; the northerly one recently completed has a depth of 36 feet on the sill at trinity high water,* and the southerly a depth of 30 feet. These open into the Gallions basin, comprising 15¼ acres of water, 32 feet deep, with six berths for steamers of the largest class. A pumping station has been erected at Gallions, having pumps throwing 125,000 gallons per minute, by which the water in the basin and docks is maintained at trinity high water, or raised above it when required for an unusually deep ship. The passage from the basin into the Royal Albert Dock is by a cut or channel, crossed by a swing bridge. The dock covers 432 acres, of which 87 are water. It is a quay dock, 490 feet wide, with a minimum depth of 27 feet, and has quay berths for thirty-three steamers of the largest class. There are two dry docks, 502 and 410 feet in length, exclusive of a cut of 20 feet at the end of each. The quays are lined with extensive warehouses, along which run railway lines connected with the general railway system.

* Trinity Standard, fixed in 1800 by the Trinity Corporation, is 12 feet 6 inches above the Ordnance Survey datum of the mean level of the sea. The inscription on a stone let into the lower external wing-wall of the Hermitage entrance to the London Docks states "Low-water mark is 17 feet and 10 inches below the lower edge of this stone, settled by the Corporation of the Trinity House, Augt. MDCCC.—*Vide* 39 & 40 Geo. III, Cap. 47, Sec. 55." (Proceedings Inst. C.E., vol. xlix, p. 88.)

Since its completion in 1880 this dock has been lighted by electricity, the work having been carried out by Messrs. Siemens Brothers. For the external illumination, twenty-nine powerful arc-lights are provided, supplied with electricity by means of continuous-current dynamo-machines. The arc-lamps are enclosed in lanterns surmounted by reflectors, and are suspended at a height of about 60 feet from latticed iron posts, the light being so distributed that ships are docked and undocked with as much facility by night as by day. For the internal lighting of the sheds, 140 movable arc-lamps of smaller size are provided. The electricity for these is supplied by alternate-current machines, and is conveyed by means of leading wires to suspenders fixed at various points along the sheds, upon which lamps are placed when any part has to be lighted up, an attendant distributing the current where required by means of commutators. To these suspenders can be attached leading wires, for supplying current to portable lamps on board ships loading or unloading alongside the quays. The motive power for the whole installation is derived from four steam engines of 20 nominal horse-power each.

The Royal Victoria Dock.—This dock occupies 200 acres, of which 90 are water. It is a jetty dock, 1000 feet wide, with a depth of 25 feet 6 inches; and has quay berths for twenty-seven steamers of the largest size, as well as for smaller vessels, and for steam colliers at four derricks. It is entered from the Royal Albert Dock through a cut or canal; whilst the passage from it into the river is by means of a tidal basin of 16 acres, and a canal and lock, having a depth of 28 feet on the sill at trinity high water.

The hydraulic machinery at these docks comprises 110 travelling and 92 fixed cranes and jiggers, a travelling coal-crane equal to 20 tons, a floating crane equal to 30 tons, and a pair of shears equal to 60 tons. The four largest steam-tugs are fitted with steam fire-engines; and fire hydrants and engines are provided along the quays. There is a complete system of goods lines throughout the docks, which centres in a goods yard at the Royal Victoria Dock, and thence communicates with the general railway system of

the country. Passenger trains run from five stations within the docks to the city at intervals of a quarter of an hour.

Besides these docks, the property of the London and St. Katharine Docks Company comprises very extensive up-town warehouses at Cutler Street, and a railway depôt at East Smithfield, and two other docks higher up the river, namely the London Docks and the St. Katharine Docks.

The London Docks cover an area of 100 acres, 60 being land and 40 water; they are nearly a mile in length, and have three entrances into the Thames. At the quays, which run along the entire docks, vessels are berthed up to 330 feet length and 24 feet draught.

The St. Katharine Docks occupy an area of 23 acres, of which 10 are water; they have an entrance into the Thames close by the Tower of London, and berth ships up to 250 feet length and 21 feet draught.

TILBURY DOCKS.

The principal works consist of a Tidal Basin, and Main and Branch Docks.

The Tidal Basin has a water area of 19 acres, and a depth of 26 feet at low-water spring tides. Two arrival and departure quays, each 600 feet long, are available for discharging and loading at all states of the tide. At the south-western quay is a coaling jetty fitted with four 30-cwt. movable hydraulic cranes. The lock connecting the tidal basin with the main dock is 80 feet wide and 700 feet long, divided into two chambers of 555 feet and 145 feet respectively. There are three pairs of wrought-iron double-skinned lock-gates; each pair weighs about 240 tons; the width of each leaf is 49 feet, and the depth from the top of the gates to the sill is 44 feet. The gates are opened and closed by hydraulic machinery, which works at a pressure of 700 lbs. per square inch in the mains, the power being supplied from the hydraulic engine-house, supplemented by accumulators placed at the north-eastern and north-western corners of the tidal basin.

In the hydraulic engine-house are three pairs of horizontal compound hydraulic engines of 100 indicated horse-power, which run at 35 revolutions per minute, and are designed to deliver 5000 gallons per hour each; steam is supplied by three Lancashire boilers, 27 feet long and 7 feet diameter. There are two 20-inch accumulators, having a stroke of 24 feet, with wrought-iron casings loaded to give the pressure of 700 lbs. per square inch.

Four dry docks are provided, two having a depth of 32 feet and two of 27 feet on the sills at ordinary spring tides; they are enclosed and divided by caissons. The emptying of the larger pair by pumping out 12,000,000 gallons of water can be performed in an hour. In the pumping-engine house are four centrifugal pumps, making 250 revolutions per minute, of sufficient capacity to raise 650 tons of water per minute; two have suctions of 7 feet diameter, and the other two of 6 feet.

The Main Dock is 1800 feet long and 600 feet wide; and each of the three Branch Docks is 1600 feet long, extending from the main dock in a north-westerly direction; the centre branch dock is 300 feet wide, and each of the two others has an average width of 250 feet. The depth throughout is 38 feet below trinity high-water mark.

There are sixty-one hydraulic travelling cranes, running on rails of $13\frac{1}{4}$ feet gauge. Each crane is mounted on an iron carriage, through which railway wagons loaded to a height of $13\frac{3}{4}$ feet can pass. The jib of each crane plumbs at 25 feet from the face of the quay coping. The lifting power is 30 cwts., and the height of lift from quay-level 60 feet. A floating steam-crane is provided, designed to lift and swing 50 tons at 25 feet, or 45 tons at 30 feet; it is capable of placing masts over 100 feet high in a ship of 50 feet beam and 32 feet from the top of the bulwarks to the water-level. There are two land and four floating steam fire-engines.

At the quays, which are $2\frac{1}{2}$ miles in length, thirty-one steam vessels of the largest size can be berthed. On the quays of the three branch docks have been erected twenty-two sheds, each 300 feet long and 120 feet wide, the height at the eaves being $12\frac{1}{2}$ feet, and at the centre of the roof 26 feet. Along the quays and in rear of the sheds are laid railway lines, which are in connection with the railway system of the country.

The electric lighting installation, supplied by Messrs. Crompton, consists of 80 arc lamps of 3,000 candles each, and 1,362 incandescent lamps of powers varying from 16 to 22 candles each. Some of the arc lamps are placed on lofty masts on the quays and railway sidings, some in the sheds, and others are portable lamps for lighting ships at the quays. The incandescent lamps are distributed throughout the sheds. The electric apparatus is driven by five engines of 500 effective horse-power in two separate engine-houses.

The whole of the works have been designed and carried out under the direction of the Engineer, Mr. Augustus Manning.

MAIN DRAINAGE SOUTHERN OUTFALL.

The Main Drainage Southern Outfall works at Crossness are situated on the south side of the Thames in Halfway-reach; and it is at this point that the discharge takes place into the river of the whole of the drainage from the south side of the metropolis, which consists of a drained area of about 50 square miles.

As the invert of the main sewer, which is $11\frac{1}{2}$ feet in diameter, is at its outlet $28\frac{1}{2}$ feet below mean spring high-water mark, the whole of the sewage has to be raised; and, during the whole of the flood tide and the last two hours of the ebb, it is stored in a large covered brick reservoir of $6\frac{1}{4}$ acres area, capable of containing 24 million gallons. The reservoir has an average depth of $14\frac{1}{4}$ feet, and a height of $16\frac{3}{4}$ feet from invert to soffit, and is sub-divided into four compartments, the level of floor being a little below that of the land outside. On the north side of the reservoir, and running parallel to it for its entire length, are three large culverts built one over the other. The middle and top culverts are connected to each of the four compartments by eight small culverts, $3\frac{3}{4}$ feet by $3\frac{1}{4}$ feet, furnished with sluices: those from the top culvert admit the sewage raised by the pumps into the reservoir; and those connected with the middle culvert discharge the sewage from the reservoir into the river. The bottom culvert is the continuation of the main sewer into the suction wells of the main pumps.

The main engine-house and boiler-house form a handsome and substantial block of buildings. The beam engines, of which there are four, are of the simple condensing type, and of very massive proportions. Each beam has eight pump plungers connected to it, and when working at 11 revolutions raises 4,257 cubic feet of sewage per minute. Each engine is of 125 nominal horse-power, and indicates a little more than double that amount; the pump valves are of the plain hinged type, faced with leather; each set of pumps delivers into its own trough, which is of steel with two air-vessels, and communicates with the top culvert. Each trough is furnished with a penstock, worked by a hydraulic piston, for which the power is obtained from a pair of duplex pumps capable of maintaining a pressure of 1,000 lbs. per square inch in the hydraulic main. The boilers, of which there are seventeen, consist of twelve Cornish of steel, 6 feet in diameter by 30 feet in length, with corrugated furnace and single-flue tube; and five Lancashire of iron, 7 feet diameter by 30 feet in length, with double flues. The boilers are supplied by two donkey-pumps, with feed-water mostly obtained from two artesian wells sunk for that purpose.

Besides the beam engines in the main buildings, there are four centrifugal pumps, 5 feet diameter, driven by two old broad-gauge locomotives, erected in one of the workshop buildings to serve as auxiliary power in times of flood; the locomotives indicate as much as 300 horse-power each. The pumps are of the vertical-spindle type, and were erected about six years since by Messrs. Easton and Anderson, of Erith.

Full plant is provided for repairs, together with spacious stores and a large water-tank to supply the workmen of the Board, who live upon the works. The water is softened by Clark's liming process. This station is also provided with its own gas works.

These works were opened in April 1865 by H.R.H. the Prince of Wales.

Sewage Experiments.—At the present time experiments are being carried out at this station on the treatment of the London sewage, and one of the four compartments of the reservoir is fitted up and

used for this purpose. The whole of the sewage discharged into the river is deodorised by chemicals. The daily average quantity of sewage discharged at this outfall is about 74 million gallons, ranging from 50 million to 150 million gallons in the 24 hours. The system of precipitation adopted involves the treatment of the sewage by means of 3·7 grains of lime in solution and 1·0 grain of proto-sulphate of iron per gallon of sewage.

For the purpose of continuing the previous experiments made at Pimlico, the construction was first authorised of plant at Crossness, capable of treating one million gallons of sewage daily, including the treatment of the sludge by presses, or by other means which might be found advisable. This plant consists of two tanks, each having a capacity of 166,666 gallons. By filling both of these three times in the twenty-four hours one million gallons of sewage can be precipitated. The arrangements for adding the chemicals are as follows. Lime-water is made in two 1000 gallon tanks, worked alternately, and is agitated by mechanical stirrers, driven by a 6 horse-power Otto gas-engine. The solution of iron is made by hand in a 100-gallon tank. As the sewage flows under the mixing-house, it receives the lime; and, after passing through the stirrers, the iron solution. The treated sewage is then run into the precipitating tanks, where it is allowed to rest for two hours. The effluent, which is of a brownish colour at times, but free from suspended matter, is drawn off from the sludge by means of a falling dam. The sludge is swept into a sump, or underground chamber, which is then closed, and the sludge driven by compressed air into the lime-mixing tank. From thence it is run into the high-pressure receiver or "monte-jus." The connection with the liming tank being closed, and a connection with the press opened, compressed air is let into the "monte-jus," and the sludge is thereby forced into the press at a pressure of 100 lbs. per square inch. The pressing of one charge in the 36-inch press occupies from 45 to 60 minutes.

In order to obtain further information and experience regarding the treatment and disposal of the sludge, one compartment of the main reservoir was afterwards arranged for the treatment of eight million gallons of sewage daily. The alterations and works

involved in this system are:—(1) an iron sludge-trough with falling dams along the length of the discharging end of No. 4 compartment; (2) the erection of plant in duplicate for preparing the lime and iron; the requisite machinery for this purpose is in great part underground, and is covered by two small brick structures, one at each end of the main engine-house; (3) the sludge-main for carrying the sludge from the reservoirs, and lift-pumps for discharging it into the sludge subsiding tanks, which are six in number and are built of concrete, each being fitted with a surface-floating outlet-pipe to carry off the top water; (4) the sludge liming shed and plant; (5) the large 5-ft. press, combined hydraulic and air engine, high-pressure cylinders and 8 horse-power steam-engine. In addition to the two presses of Messrs. Johnson and Son, a third press, constructed by the Radial Filter Press Co., of which Mr. D. K. Clark is the engineer, has been obtained after very extensive trials.

For the purpose of illuminating the underground reservoir when the men are sweeping out the sludge, a system of electric incandescent lighting has been introduced. The dynamo is driven by the gas engine of the one million gallon plant, and supplies the current for twenty-five lamps. The whole installation has worked very satisfactorily and economically.

The total quantity of sewage treated by the two sets of plant up to the beginning of June 1886 was 490 million gallons. The wet sludge obtained therefrom amounted to 15,100 tons. This quantity, on further settlement in the special subsiding tanks, was reduced to 8,970 tons, of which 5,034 tons have been pressed into 1,470 tons of cake.

The following statement shows the estimate of the Royal Commission, as against the actual results obtained from the treatment of nearly 500 million gallons of sewage at Crossness:—

Per day of 150 million gallons.	Royal Commission Estimates.	Board's Results.
	Tons.	Tons.
Wet sludge as precipitated	4,500	4,620
Reduced by second settlement in special tanks	Not contemplated by Royal Commission	2,745
Pressed cake	900	803

Deodorisation.—The operations connected with the deodorisation of the sewage are now confined to the application of the chemicals employed, namely manganate of soda, and sulphuric acid; the manufacture of manganate at Crossness is no longer carried on, in consequence of manufacturers now being able to supply a sufficient quantity at low prices. The original furnaces and pans have been cleared away, and the surface made good. The mechanical plant is still standing, the shed in which it is placed being used as a store-house for reserve stocks.

The two points for observation are the acid tank and the deodorising mills. The acid tank is a lead-lined cistern, 20 feet by 12 feet by 4 feet, and holds, when nearly full, 50 tons of sulphuric acid. The tank is charged direct from the steam barge by means of a pump on the barge. The outlet fills two small chambers alternately, which are used for measuring the quantity of acid withdrawn.

The deodorising mills consist of two pairs of edge-runners or mortar mills, 7 feet diameter, fitted with curtain-guard and conduit. Each pair is worked by an 8 HP. semi-portable engine, which also drives a centrifugal pump to supply water to pans; the system is thus in duplicate, in order to avoid the risk of a complete breakdown in case of accident. A precisely similar set of plant for deodorising is in operation at the Barking outfall from the north side of the metropolis.

The manganate of soda is ground by the mills, through the pans of which a constant stream of water is kept flowing. The solution of manganate of soda so formed flows away to the outlet culvert by means of an open channel. On its way a stream of sulphuric acid is discharged into it, with the result that the manganate of soda (a green compound) is immediately converted into permanganate of soda (a red compound), which has more intense oxidising properties than the simple manganate. This process of deodorisation is in operation at twenty-three stations within the metropolis, in addition to the outfalls.

MESSRS. YARROW AND CO.'S WORKS.

The principal things seen here are torpedo boats in course of construction for the British and Foreign governments. In this establishment the entire process is seen of making the machinery and also building the vessels.

SUKKUR BRIDGE CANTILEVERS.

The Sukkur Bridge, the cantilevers of which are being built by Messrs. Westwood, Baillie and Co., London Yard Iron Works, Poplar, is intended to span the Indus at the town of Sukkur, where the river is divided into two streams flowing through the Sukkur Pass and the Rohri Pass. Sukkur is about 300 miles from the mouth of the Indus; and there is at present a steam ferry connecting the railway from Karachi and the railway to Quetta on the west side of the river with the lines to Lahore and Delhi on the east side. The only bridge over the Indus at present is at Attock, which is 500 miles north of Sukkur, and near Peshawur in the extreme north-west of India. The Sukkur bridge will therefore form a most important link in the chain of frontier lines now being built, and will afford the same direct communication to the Bolan Pass and Candahar that the Attock bridge does to Peshawur and Cabul. The Sukkur Pass has already been bridged by three spans of 278 feet, 230 feet, and 93 feet; and the Rohri Pass is to be crossed by the Sukkur bridge now constructing in one span of 790 feet in the clear, or 820 feet between centres of main pillars. The river in this pass is of great depth and swiftness, the current in floods having a velocity of ten miles per hour. The bed of the river and its banks are of limestone rock. Above and below Sukkur the river is wide and sluggish, flowing like most Indian rivers through an alluvial plain. Owing to the great depth to which the piers would have had to be sunk, and the great length of the bridge, it was thought that a bridge over any wider part of the river would have been more costly than the Sukkur bridge, even with its inevitably large span. The type of bridge to be adopted was the subject of long and careful consideration by the government authorities both in India and in England, the result being the adoption of the cantilever system. The cantilevers are each 310 feet

in length, and the centre span resting on them is to be a lattice girder of 200 feet. As there is but one span, anchorage has to be provided on each side. The following are the main dimensions of the bridge:—extreme height of cantilever from under bedplate, 173 feet; height of rail from under bedplate, 40 feet; length of back guys, 280 feet and 300 feet; width of bridge between centres of main members of bedplate, 100 feet; width of bridge between centres of main members at end of cantilever, 20 feet; width between centres of back guys, 20 feet. The bridge is for a single line of railway of 5 feet 6 inches gauge. It is to be constructed entirely of mild steel plates and bars, supplied by Messrs. Beardmore, Parkhead, Glasgow, ranging from $1\frac{1}{4}$ inch to $\frac{5}{16}$ inch in thickness, and riveted together with steel rivets. The long struts are rectangular in section; each corner of the rectangle consists of a curved plate with angle-bars on its edges, and the faces of the rectangle are occupied by transverse and diagonal bracing. Longitudinally the struts are curved on all four faces, tapering from the middle towards the ends. The roadway girders are of steel, 4 feet 6 inches in depth and at a uniform distance of 18 feet apart; the cross girders are spaced 8 feet apart. The floor of the bridge is of corrugated steel plating. The back guys are more heavily strained than any other members; the stress provided for in each of the two guys of the cantilever amounts to 1,200 tons, and arises firstly from a load of 300 tons imposed by the centre span upon the nose of the cantilever, secondly from the dead weight of the cantilever itself, thirdly from a rolling load covering the cantilever, and fourthly from wind. The anchors are buried in a large mass of concrete, and are built up of steel plates and angle-bars. Each anchor measures 32 feet by 12 feet in a plane at right angles to the line of stress. The total weight of steel in the two cantilevers, including the back guys and anchors but excluding the central span, is nearly 3,000 tons. Owing to the fact that no staging can be employed in the erection of the bridge in India, and to the difficulty of carrying out work at the site, it was thought advisable to adopt with these cantilevers the same plan that is pursued with all other bridges for India, namely, to erect them in England complete, in order to ensure a perfect fit and accuracy of workmanship

in all parts. A great saving of time and expense is thereby effected in the erection of the work abroad, and a much better result is obtained than could be got in any other way. On this plan the last span of the Sutlej bridge, weighing 420 tons, was erected in forty-five working hours. The bridge has been designed by Mr. A. M. Rendel, the consulting engineer to the Indian government.

Among other large bridges built at these works for the Indian government are the Chenab bridge of sixty-four spans, the Empress bridge of sixteen spans over the Sutlej, and the Attock bridge of five spans over the Indus.

MEMOIRS.

Sir John Anderson, LL.D., F.R.S.E., was born at Woodside, near Aberdeen, on 9th December 1814, a few months after the death of his father, who was a merchant in that village. On leaving the village school, at the age of thirteen, he was apprenticed as a mechanic at the Woodside Cotton Works of Messrs. Gordon Barron and Co., under his step-father, Mr. Irvine Kempt, where he remained for about ten years. Leaving Woodside in 1839, during the next three years he followed his profession in the works of Mr. Penn, Greenwich; Messrs. Sharp Roberts and Co., and Messrs. William Fairbairn and Co., Manchester; and Mr. David Napier, London. In 1842 he was appointed, on the recommendation of Mr. Napier, to take charge of the brass-gun foundry and other new works at Woolwich arsenal. There he gradually introduced much needed reforms in the system of working, and invented new machines to be used in the construction of cannon and in the casting of rifle bullets. During the first eight years of his service, he devised no fewer than sixteen new and valuable machines for executing different processes in the manufacture of guns, bullets, percussion caps, &c. One bullet machine turned out 40,000 bullets per hour; and another of his inventions was a machine for automatically granulating gunpowder. In 1853 the valuable services which had been rendered by him in several branches of the ordnance service by his inventions and adaptations of machinery received substantial recognition from the government. In the same year he was appointed to report upon the capabilities of the government rifle factory at Enfield for manufacturing bayonets by machinery; and the result of the enquiry was the establishment by the government of a small-arms factory at Enfield in entire accordance with his plans, where after the first few years were produced annually 100,000 muskets with bayonets complete, at a cost of less than £2 each. In 1854,

during the Crimean war, he erected within two months a shell factory covering more than 3000 square yards, and containing the necessary steam-engines, steam-hammers, and machines of various descriptions, many of them original and specially devised, the whole of which was in full operation within that time. In 1859 the manufacture of Armstrong guns was taken up by the government, and he was chosen to superintend the work as chief inspector of machinery. In 1866 he was appointed superintendent of machinery to the war department. This post he occupied till 1872, when he retired after thirty years of service. He became a Member of this Institution in 1856, and was elected a Member of Council in 1861, and a Vice-President in 1868. In 1858 he contributed a paper on some applications of the copying or transfer principle in the production of wooden articles (Proceedings, page 237); and in 1862 another on the application of the copying principle in the manufacture and rifling of guns (Proceedings, page 125). He also published a work on the strength of materials, besides many technical pamphlets. The honour of knighthood was conferred upon him in 1878. To his native village of Woodside he presented a building for a permanent free library, together with 50,000 volumes, forming one of the most complete of its kind in Scotland. His death occurred on 28th July 1886, at his residence, Fairleigh, St. Leonards-on-Sea, at the age of seventy-one, after a fortnight's illness from an aggravated bronchial affection.

George Bodden, only son of Mr. William Bodden, of the Hargreaves Spindle and Flyer Works, Oldham, was born at Oldham on 30th March 1850, and was educated at Rossall College, Fleetwood. After serving fourteen months in the engineering works of Mr. Joseph Bickerton, Oldham, and fifteen months in the engineering tool works of Messrs. William Heap and Co., Ashton-under-Lyne, as draughtsman and fitter, he entered the cotton-spinning mill of Messrs. Bodden and Mercers, Oldham, where he attained the position of manager. He afterwards entered Messrs. Bodden and Mercers' iron works, and worked as apprentice, and then as journeyman smith, turner, and draughtsman, in their machine, tool, spindle, and fly departments.

He ultimately became manager, and held that position for some years. In 1880 he became partner with his father in the firm of Messrs. William Bodden and Son, spindle and flyer manufacturers and machinists, Hargreaves Works, Oldham. He died on 6th September 1886, at the age of thirty-six, from the effects of injuries received in an accident on 24th July, when he was thrown from his horse. He became a Member of this Institution in 1883; and had but recently been appointed a magistrate for the borough of Oldham.

Rowland Childe, eldest son of Mr. Joseph Childe who was mining engineer to the Low Moor Iron Company, was born at Flockton, near Wakefield, on 29th April 1826, and was educated at Emley Grammar School. In 1842 he was articled to Mr. Henry Holt, of Wakefield, at that time the chief engineer in the West Riding of Yorkshire, with whom he was engaged in projecting or opposing numerous lines of railway in all parts of the kingdom, and afterwards in sinking and laying out several collieries and iron works in Yorkshire. In 1860 he joined Mr. Holt in partnership, which lasted until the death of the latter in 1869; since which date he acted as mining engineer to most of the properties in his district, and as mining adviser to the North Eastern Railway, and was continually engaged in arbitrations. His advice was frequently sought on engineering and other questions, in connection with which his prudence was of great value. On the occasion of the summer meeting of this Institution in Leeds in 1882, he kindly furnished the map of the coal and ironstone district of Leeds, and the section of the strata, illustrating the paper on the history of engineering in Leeds (see Proceedings 1882, page 276 and Plates 49 and 50). His death took place on 30th July 1886, at the age of sixty. He became a Member of this Institution in 1883.

Alexander Jack, only son of Mr. James Jack, founder of the Victoria Engine Works, Liverpool, was born in Liverpool in October 1846. After serving some time at his father's works he was apprenticed to Messrs. Randolph Elder and Co., Glasgow, where he served in the pattern shop and erecting shop, and in both engineering

and shipbuilding drawing-offices. On his return to Liverpool in 1868 he was engaged in the drawing office, and afterwards as outside manager; and at the end of 1871 was admitted a partner in the firm of Messrs. James Jack, Rollo and Co. On the death of his father in 1880, the practical direction of the business devolved upon himself, Mr. Rollo having retired from the firm; and in 1884 he became sole partner, and started shipbuilding at Seacombe on the Mersey. Owing however to depression of trade and to trouble with workmen, the latter venture did not prove a financial success, and involved him in difficulties which no doubt shortened his life; for after a long illness he died on 7th March 1886 at the age of thirty-nine. He became a Member of this Institution in 1872.

John Pattinson was born at Carlisle on 16th November 1819, and was educated at the Carlisle grammar school. He served his time with Messrs. Dixon of Carlisle, and was for eight years with Messrs. Adams and Co., Fairfield Works, Bow, London. In 1850 he became assistant locomotive superintendent on the Cork and Bandon Railway, and remained there about six years, till he went to Russia and became assistant locomotive superintendent on the St. Petersburg and Moscow Railway. He left there to become locomotive superintendent of the Moscow Jaroslaff railway, where he remained six years. Thence he removed to the Riazan and Kosloff Railway, where he continued until 1886, when he retired from active work. His death occurred in London on 12th April 1886, from fatty degeneration of the heart, at the age of sixty-six years. He became a Member of this Institution in 1881.

Thomas Wood was born at Northlew, Devonshire, on 21st March 1849. Having been educated at the Dowlais schools, he was apprenticed by Mr. Menelaus at the Dowlais Works. After passing through the workshops and drawing office, he was made assistant engineer in 1868. In 1873 he was appointed by Sir George Elliot to reconstruct the Aberaman Works, which had been idle for a number of years; and shortly after they had been successfully started, he became engineer to the West Cumberland Iron and

Steel Works, Workington, where he made many alterations and improvements, including the conversion of a marine engine into a reversing rolling-mill engine. In 1877 he was appointed chief engineer to the Ebbw Vale Steel Iron and Coal Works, for which he designed new blast-furnace plant at Victoria, two new cogging mills at Ebbw Vale, and numerous other works. Of the blooming mill with balanced top roll a description was given to this Institution in 1885 (Proceedings, page 292). His death took place from an attack of pneumonia after a few days' illness on Saturday, 17th July 1886, at the age of thirty-seven. He became a Member of this Institution in 1885.

Robert Wyllie, son of Mr. James Wyllie, farmer, of Border, Saltcoats, was born on 25th March 1850. After being educated at a local school, he assisted his father for a short time on his farm, but soon afterwards became an apprentice in the engineering department of Messrs. Randolph and Elder's works, Govan. Devoting his evenings to the study of mechanics and mathematics, he passed rapidly through the practical and theoretical departments of the business, and was afterwards appointed assistant manager of the engineering works at Fairfield, where he gained a thorough mastery of the principles and practice of marine engineering. In 1882 he became the general manager for Messrs. Thomas Richardson and Sons of the Hartlepool Engine Works, Hartlepool. Here he carried out such extensive alterations as enabled the works to compete successfully with the Clyde engineers in the highest class of marine engineering. Having devoted much attention to the application of the triple-expansion principle to marine engines, he had at the time of his death just completed a paper on the subject for this Institution. His death took place on 21st July 1886, at the age of thirty-six, from injuries sustained in an accident on 18th June, through the failure of the sheer-legs employed in the shipment of some marine boilers at the Hartlepool docks. He became a Member of this Institution in 1883.

COMPOUND LOCOMOTIVES IN RUSSIA.

Locomotive and Apparatus in Testing Shed.

Fig. 1. *Side Elevation of Locomotive.*

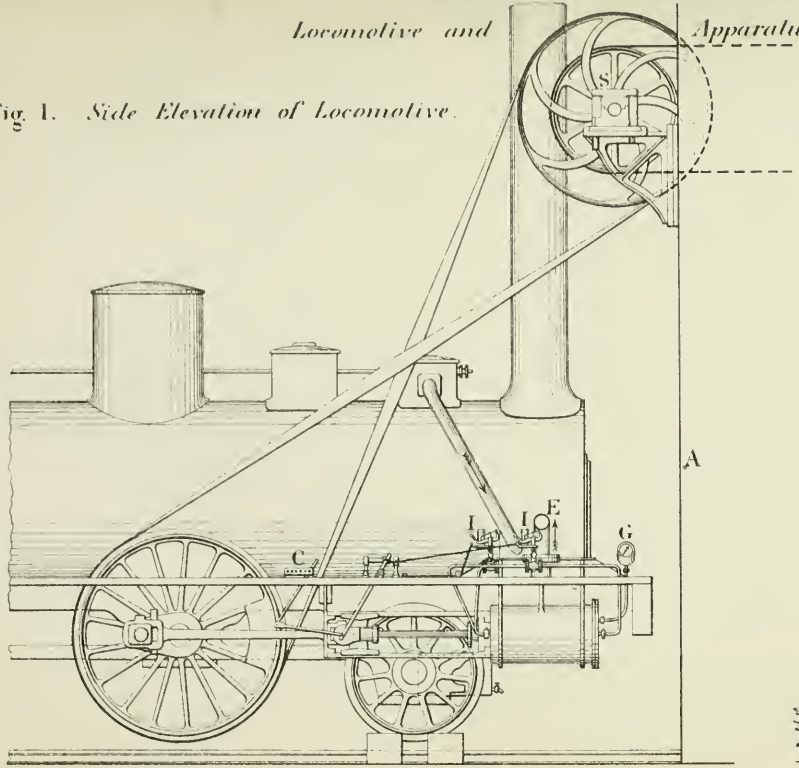
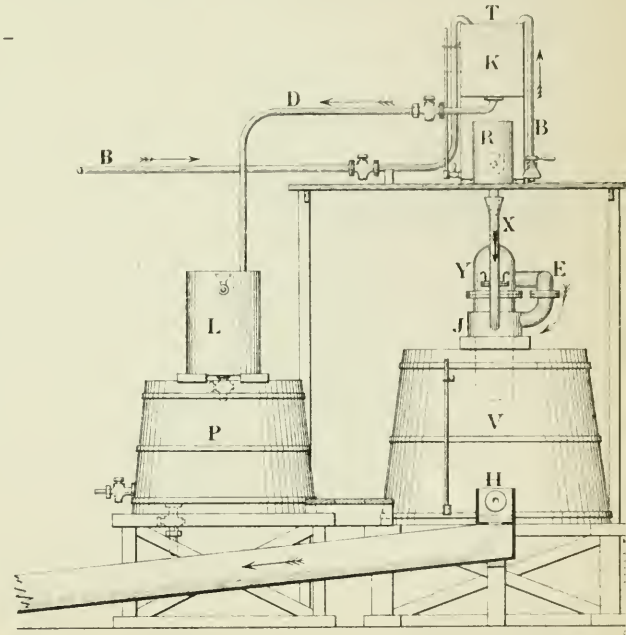


Fig. 2. *Side Elevation of Apparatus.*



(*Proceedings Inst. M. E. 1886.*) *Scale 1/60th*

0 5 10 15 20 Feet.

COMPOUND LOCOMOTIVES IN RUSSIA.

Locomotive and Apparatus in Testing Shed.

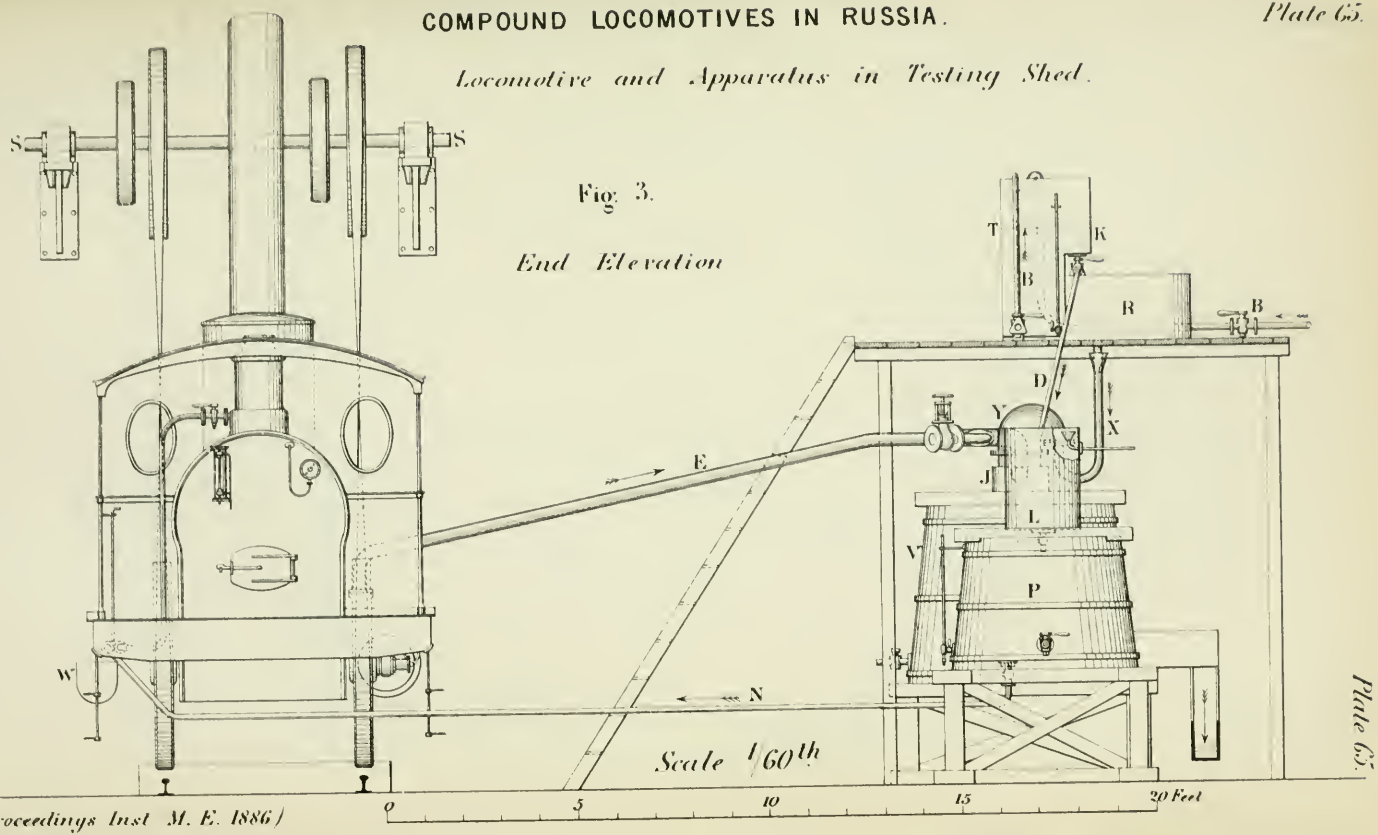
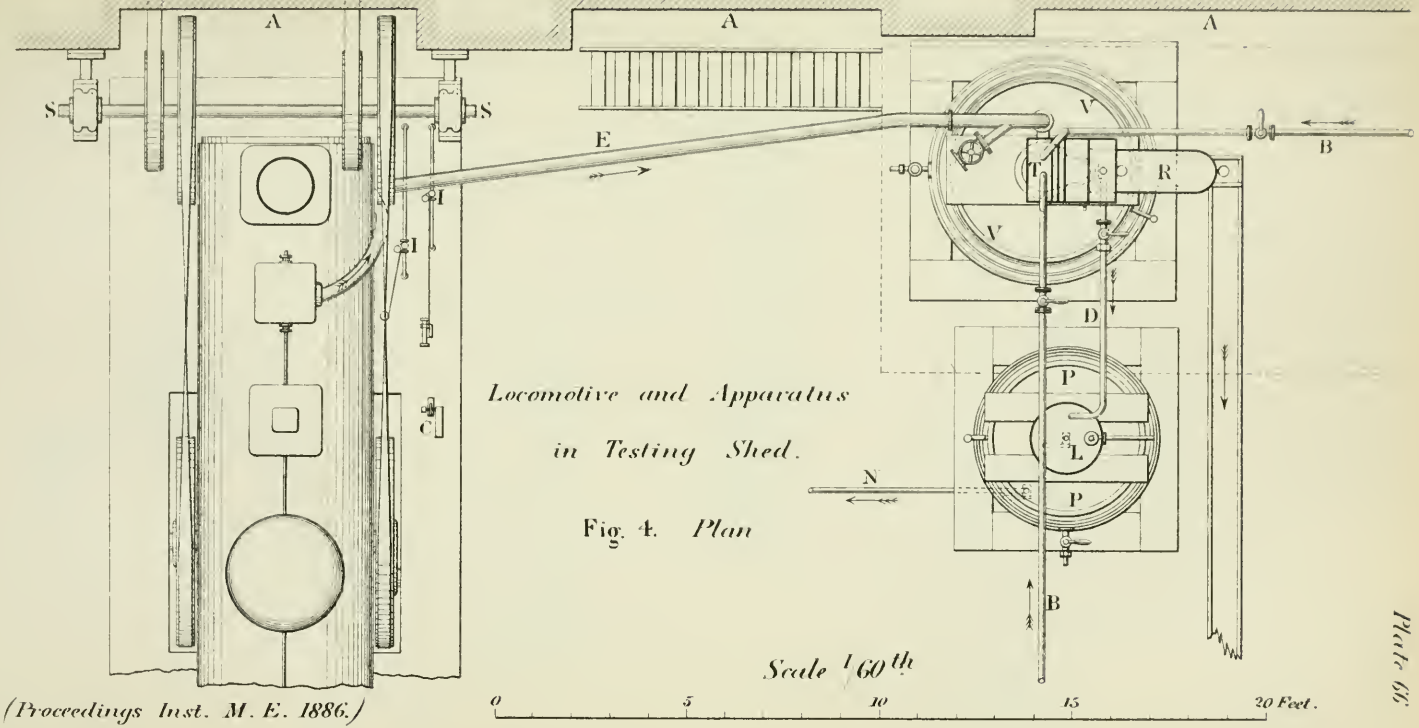


Fig. 3.

End Elevation

Plate 65.

(Proceedings Inst M. E. 1886)



Locomotive and Apparatus in Testing Shed.

Fig. 4. *Plan*

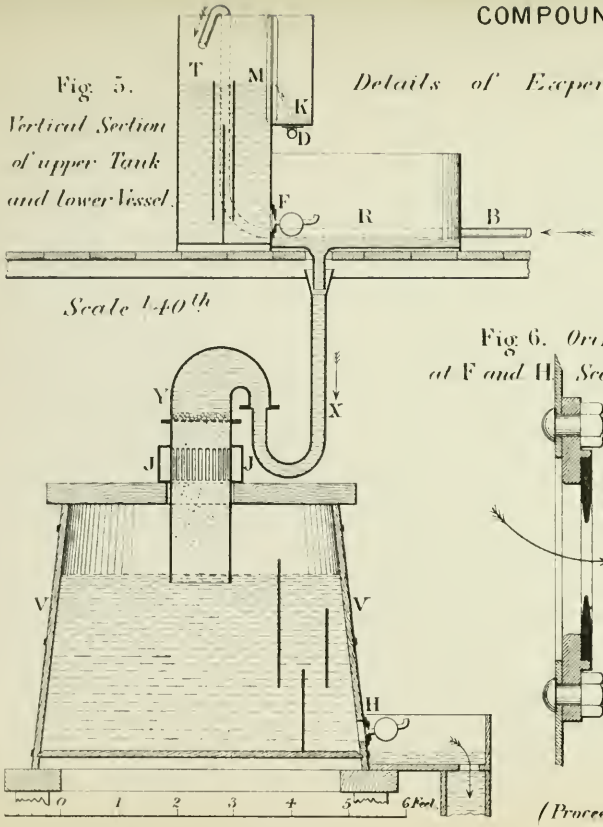
Scale 1/60th

(Proceedings Inst. M. E. 1886.)

Plate 66.

Fig. 5. *Vertical Section of upper Tank and lower Vessel.*

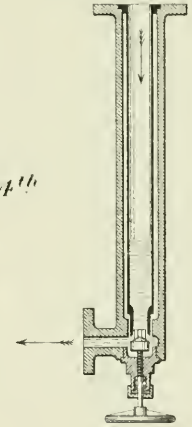
Details of Experimental Apparatus.



Scale 1/40th

Fig. 6. *Orifice at F and H Scale 1/4th*

Fig. 7 *Steam-Trap for draining Jackets.*



Water Gauge with Internal Baffle Plates.

Fig. 8. *Side Elevation.*

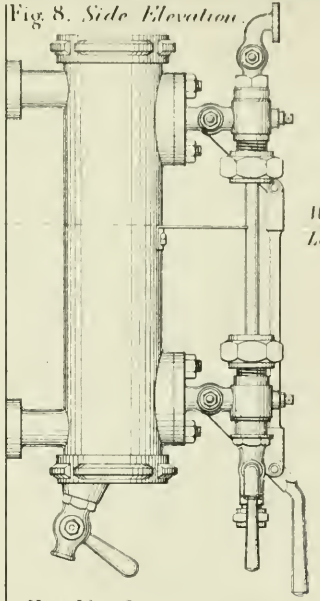


Fig. 9. *Section*

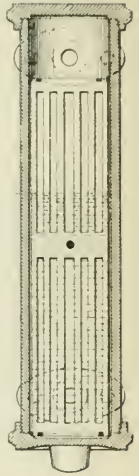
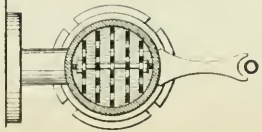


Fig. 10. *Cross Section.*



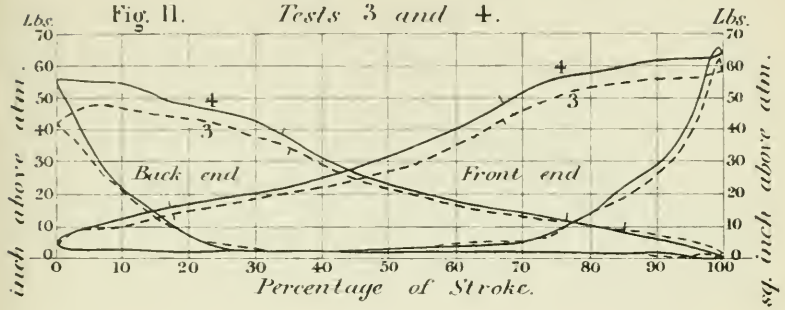
Scale 1/8th

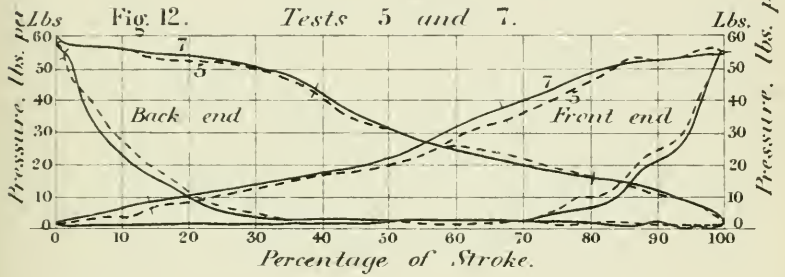
(Proceedings Inst. M. E. 1886.)

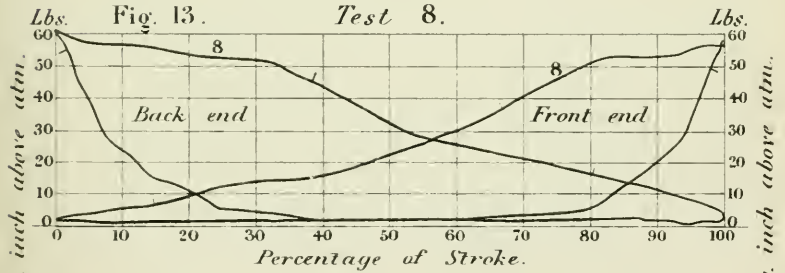
Plate 67

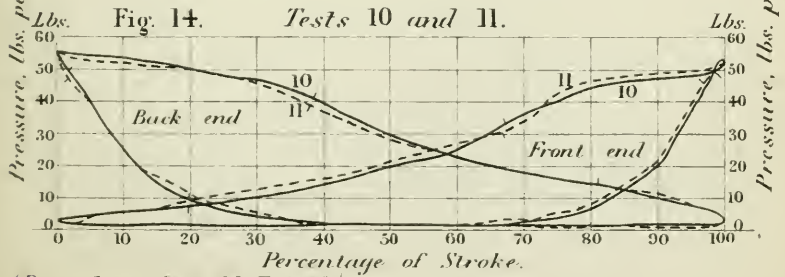
Indicator Diagrams from ORDINARY *Locomotive A22.*

—— *Jackets working.* *Jackets* NOT *working* - - - -





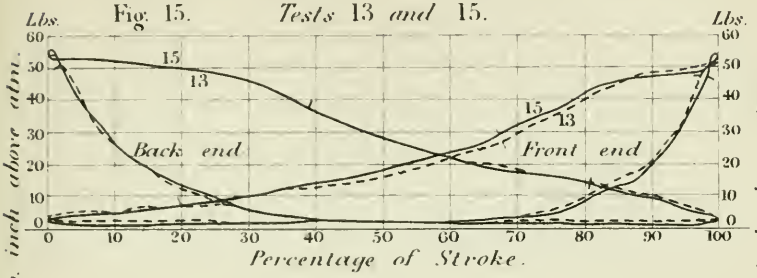


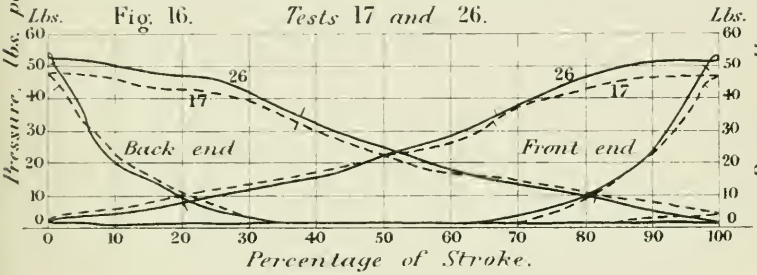


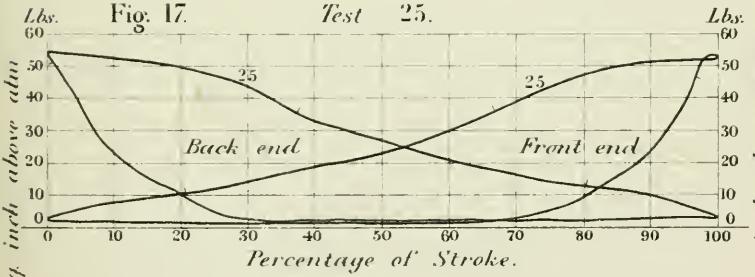
(Proceedings Inst. M. E. 1886.)

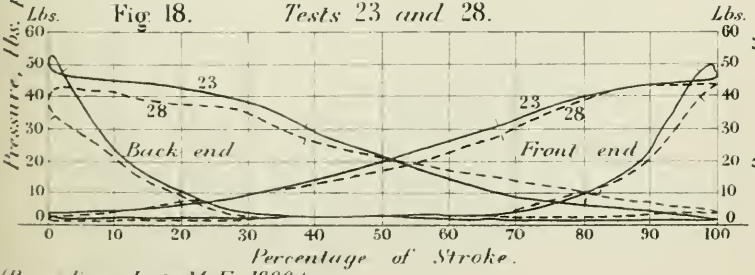
Indicator Diagrams from ORDINARY *Locomotive* A 22.

—— *Jackets working* *Jackets* NOT *working* - - - -









(Proceedings Inst. M.E. 1886.)

Indicator Diagrams from ORDINARY *Locomotive* A 22.

—— *Jackets working.* *Jackets* NOT *working* - - - -

Fig. 19. *Tests* 29 *and* 33.

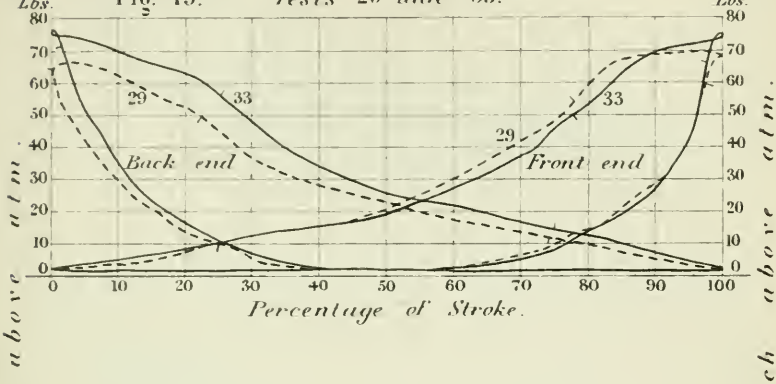


Fig. 20. *Test* 32.

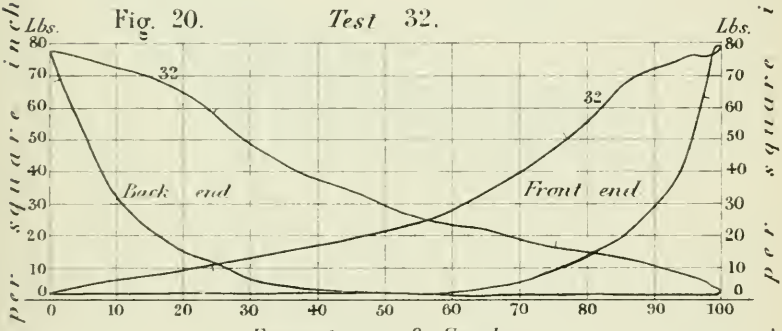
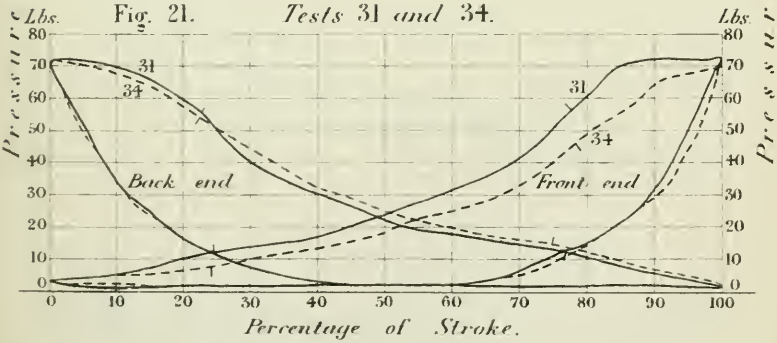
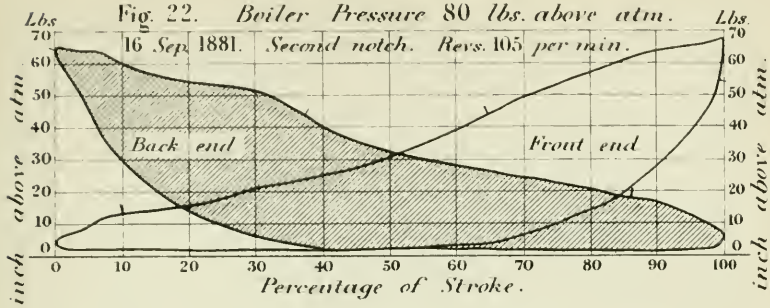


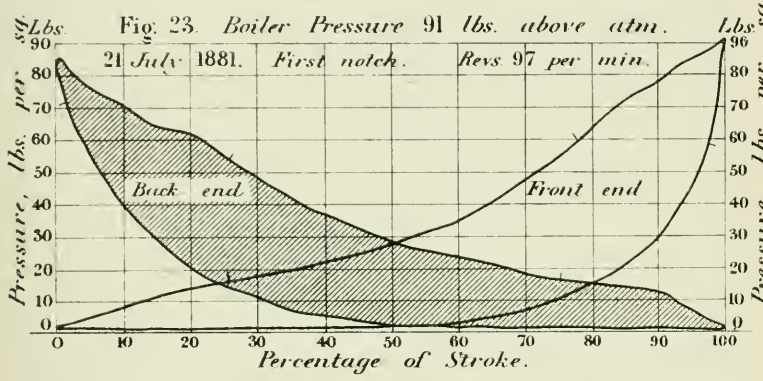
Fig. 21. *Tests* 31 *and* 34.



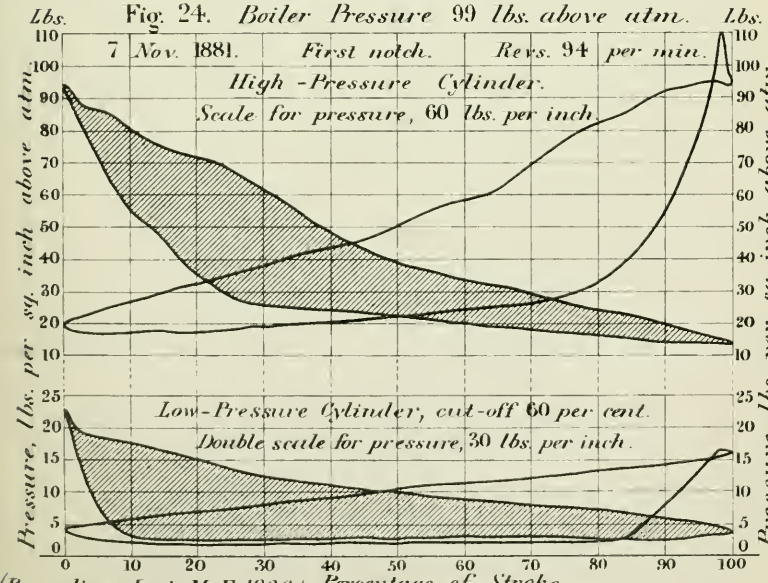
(Proceedings Inst. M. E. 1886.)

Indicator Diagrams from ORDINARY *Locomotive* A 21.
Jackets NOT *working.*


Lbs. per sq. inch above atm.
Fig. 22. Boiler Pressure 80 lbs. above atm.
16 Sep. 1881. Second notch. Revs. 105 per min.
Back end
Front end
Percentage of Stroke.

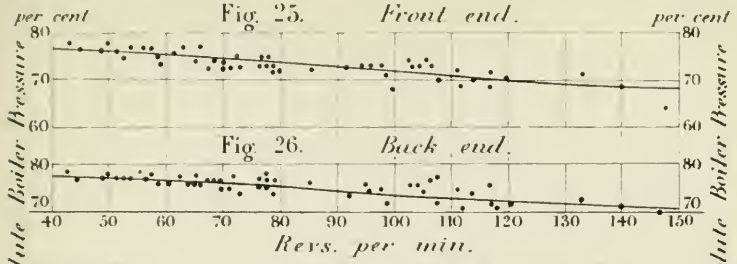

Lbs. per sq. inch above atm.
Fig. 23. Boiler Pressure 91 lbs. above atm.
21 July 1881. First notch. Revs. 97 per min.
Back end
Front end
Percentage of Stroke.

Indicator Diagrams from COMPOUND *Locomotive* A 7.
Jackets NOT *working.*

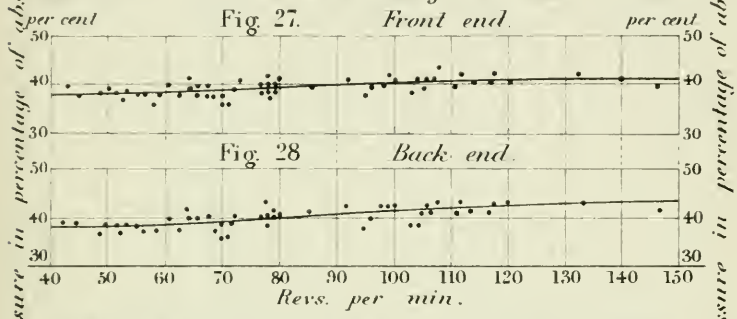

Lbs. per sq. inch above atm.
Fig. 24. Boiler Pressure 99 lbs. above atm.
7 Nov. 1881. First notch. Revs. 94 per min.
High-Pressure Cylinder.
Scale for pressure, 60 lbs. per inch.
Low-Pressure Cylinder, cut-off 60 per cent.
Double scale for pressure, 30 lbs. per inch.
Percentage of Stroke.

COMPOUND *Locomotive A 7, High-Pressure Cylinder.*

Mean Forward Pressure in Percentage of Boiler Pressure.

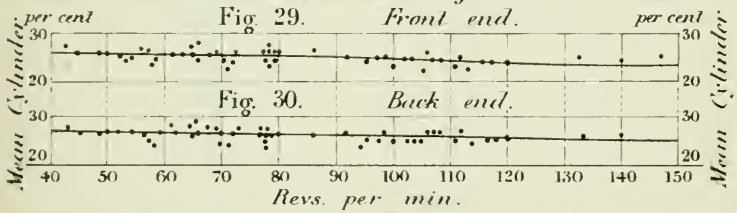

per cent
Fig. 25. Front end.
per cent
Fig. 26. Back end.
Mean Forward Pressure in percentage of absolute Boiler Pressure
Revs. per min.

Mean Back-Pressure in Percentage of Boiler Pressure.

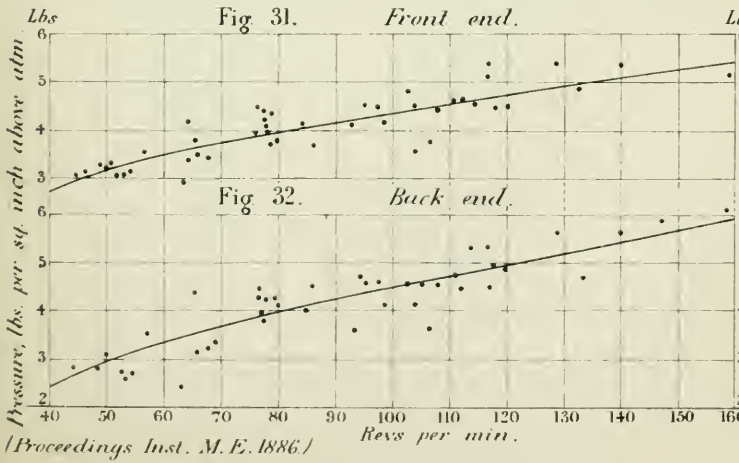


COMPOUND *Locomotive A 7, Low-Pressure Cylinder.*

Mean Forward Pressure in Percentage of Boiler Pressure


per cent
Fig. 29. Front end.
per cent
Fig. 30. Back end.
Mean Cylinder Pressure in percentage of absolute Boiler Pressure
Revs. per min.

Mean Back-Pressure in lbs. per square inch above atm.



(Proceedings Inst. M.E. 1886.)

COMPOUND LOCOMOTIVES IN RUSSIA.

Fig. 33. *Diagram from Speed-Indicator.*

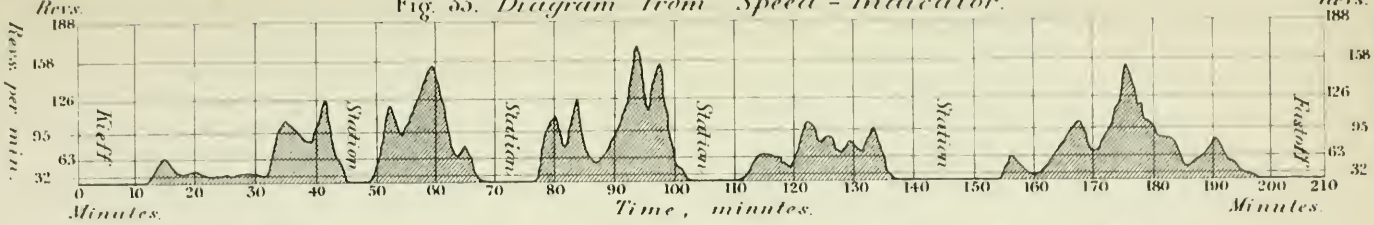


Fig. 34. *Consumption of Water per I.H.P. per hour according to degree of Expansion in* COMPOUND *Locomotive* A 7.

Jackets NOT *working*

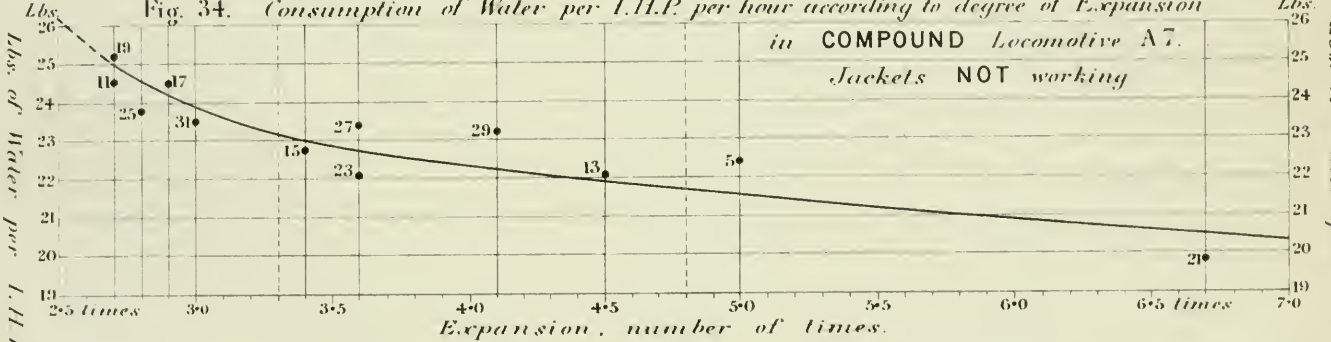
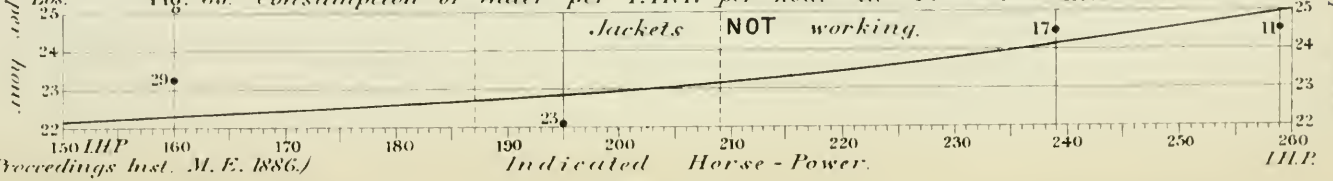


Fig. 35. *Consumption of Water per I.H.P. per hour in* COMPOUND *Locomotive* A 7.

Jackets NOT *working.*



(*Proceedings Inst. M.E. 1886.*)

Indicator Diagrams from ORDINARY *Locomotive* A 22.

Jackets NOT *working.*

Fig. 36. *Boiler Pressure* 127 *lbs above atm. Revs.* 75 *per min.*

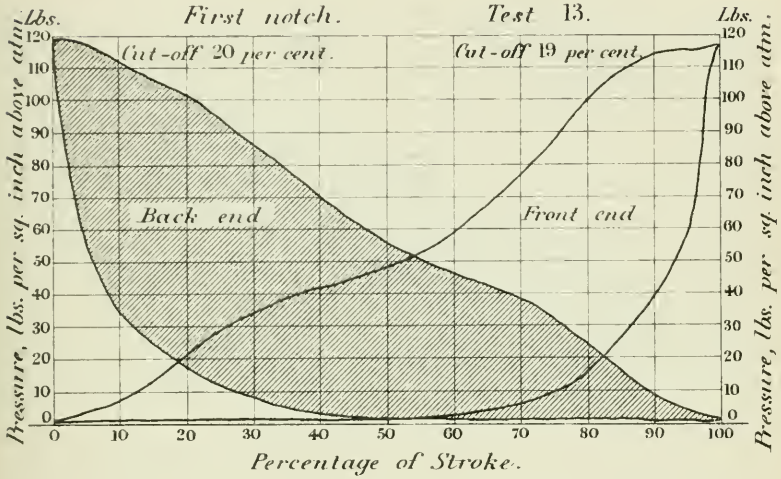
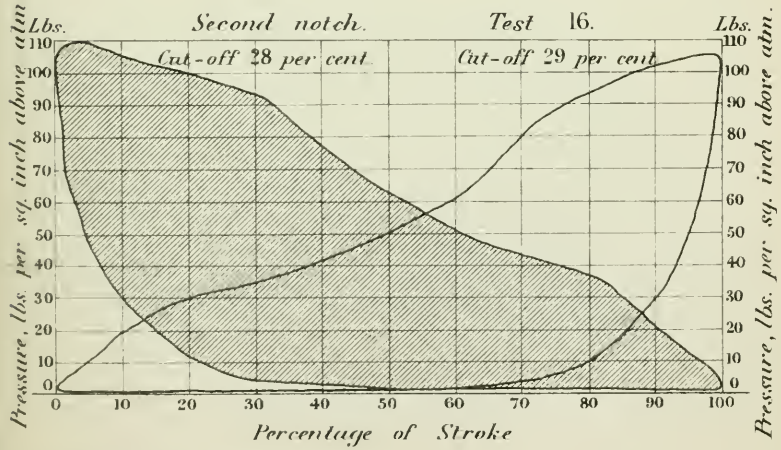


Fig. 37 *Boiler Pressure* 126 *lbs. above atm. Revs.* 90 *per min.*


Lbs.
Second notch.
Test 16.
Lbs.
Cut-off 28 per cent.
Cut-off 29 per cent.
Pressure, lbs. per sq. inch above atm.
Pressure, lbs. per sq. inch above atm.
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke

(Proceedings Inst. M. E. 1886.)

Indicator Diagrams from ORDINARY *Locomotive* A 22.

Jackets NOT *working.*

Fig. 38. *Boiler Pressure* 127 *lbs. above atm. Revs.* 80 *per min.*

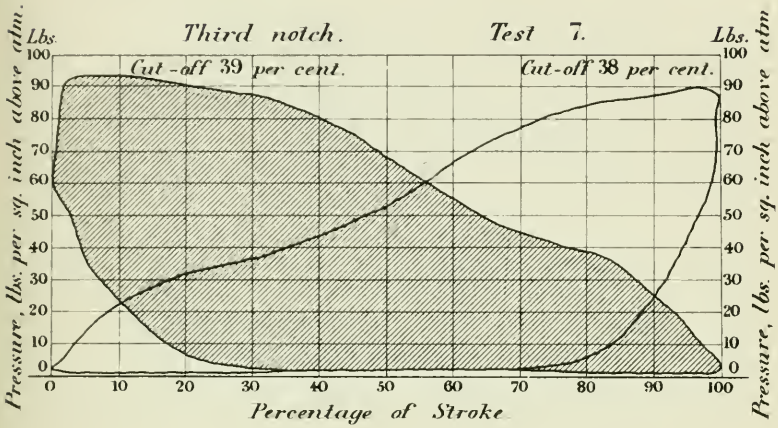
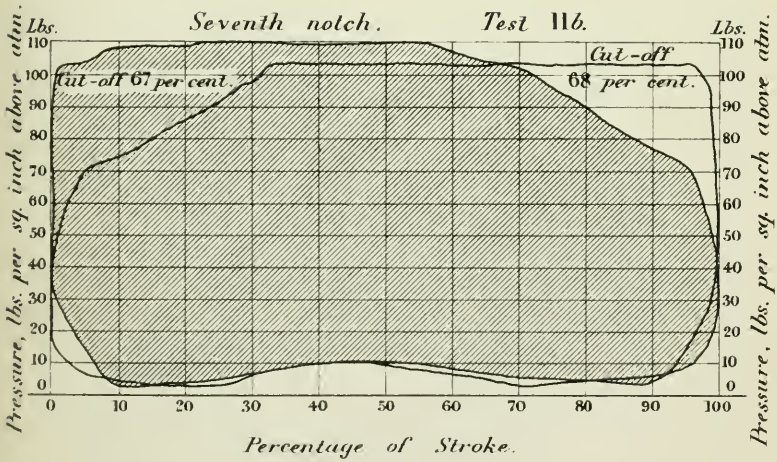

Lbs.
Third notch.
Test 7.
Lbs.
Cut-off 39 per cent.
Cut-off 38 per cent.
Pressure, lbs. per sq. inch above atm.
Pressure, lbs. per sq. inch above atm.
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke.

Fig. 39. *Boiler Pressure* 130 *lbs. above atm. Revs.* 61 *per min.*


Lbs.
Seventh notch.
Test 116.
Lbs.
Cut-off 67 per cent.
Cut-off 68 per cent.
Pressure, lbs. per sq. inch above atm.
Pressure, lbs. per sq. inch above atm.
0 10 20 30 40 50 60 70 80 90 100
Percentage of Stroke.

(Proceedings Inst. M. E. 1886.)

COMPOUND LOCOMOTIVES IN RUSSIA. *Plate 76.*

Indicator Diagrams from COMPOUND *Locomotive A 7.*

Jackets NOT *working.*

Fig. 40. *Boiler Pressure* 135 *lbs above atm.* *Revs.* 86 *per min.*

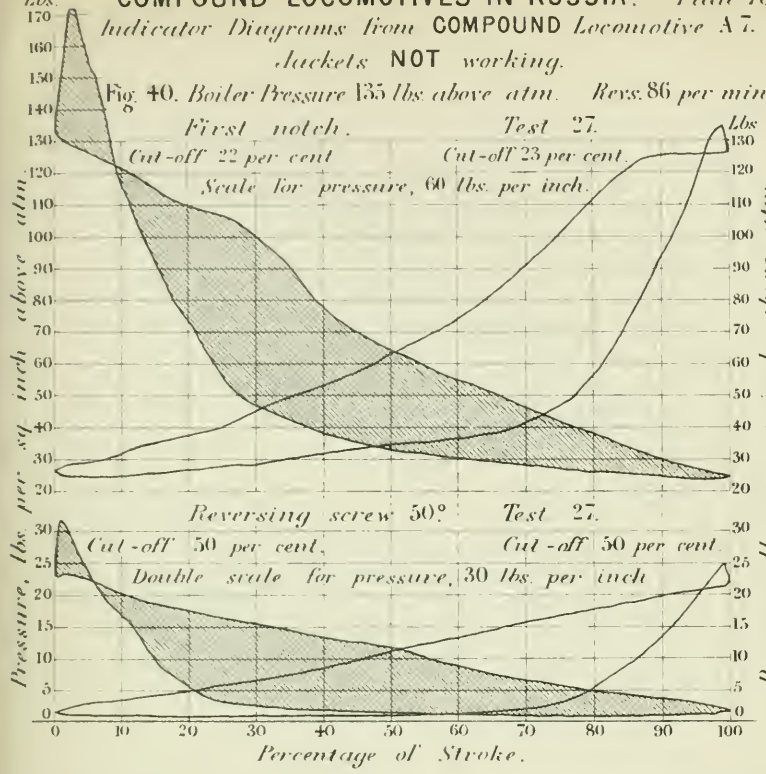
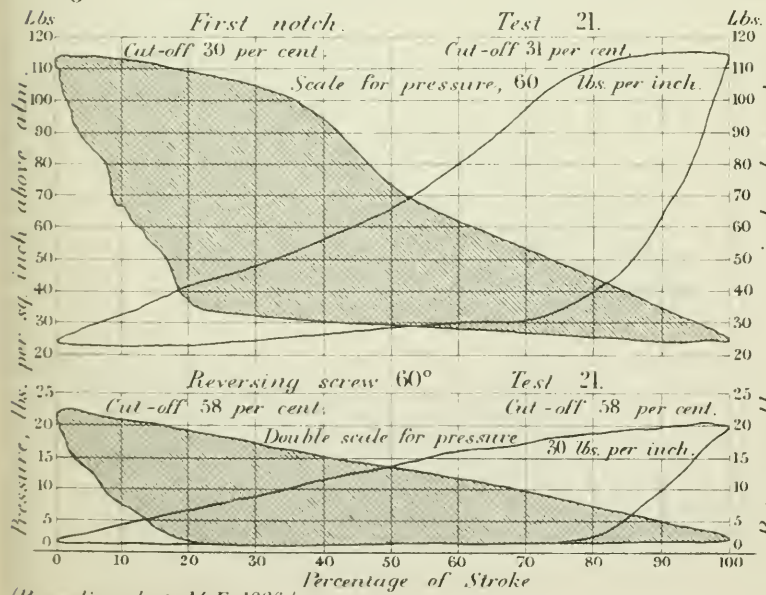

Lbs.
First notch.
Test 27.
Cut-off 22 per cent
Cut-off 23 per cent.
Scale for pressure, 60 lbs. per inch.
Lbs per sq. inch above atm.
Reversing screw 50°
Test 27.
Cut-off 50 per cent.
Cut-off 50 per cent.
Double scale for pressure, 30 lbs. per inch
Pressure, lbs. per sq. inch above atm.
Percentage of Stroke.

Fig. 41. *Boiler Pressure* 120 *lbs above atm.* *Revs.* 83 *per min.*



(Proceedings Inst M.E. 1886.)

Indicator Diagrams from COMPOUND *Locomotive* A 7.

Jackets NOT *working.*

Fig. 42 *Boiler Pressure* 138 *lbs. above atm. Revs.* 89 *per min.*

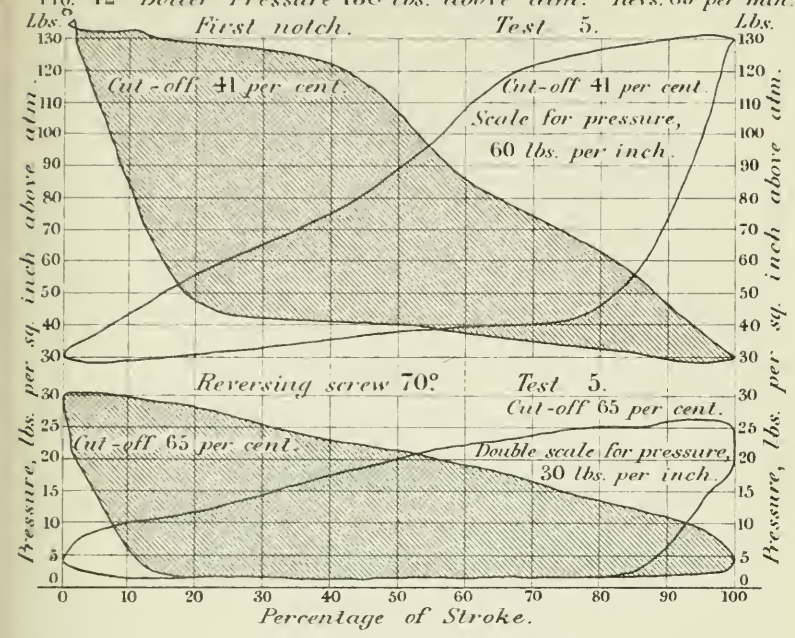
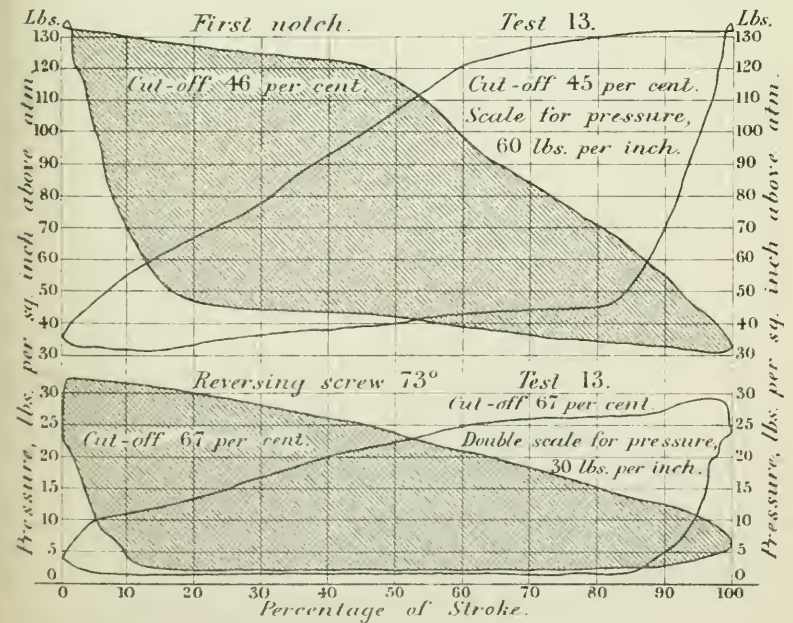


Fig. 43. *Boiler Pressure* 140 *lbs. above atm. Revs.* 65 *per min.*



(Proceedings Inst. M. E. 1886.)

Indicator Diagrams from COMPOUND *Locomotive A 7.*
Jackets NOT *working.*

Fig. 44. *Seventh notch. Boiler Pressure* 131 *lbs. above atm. Test* 31

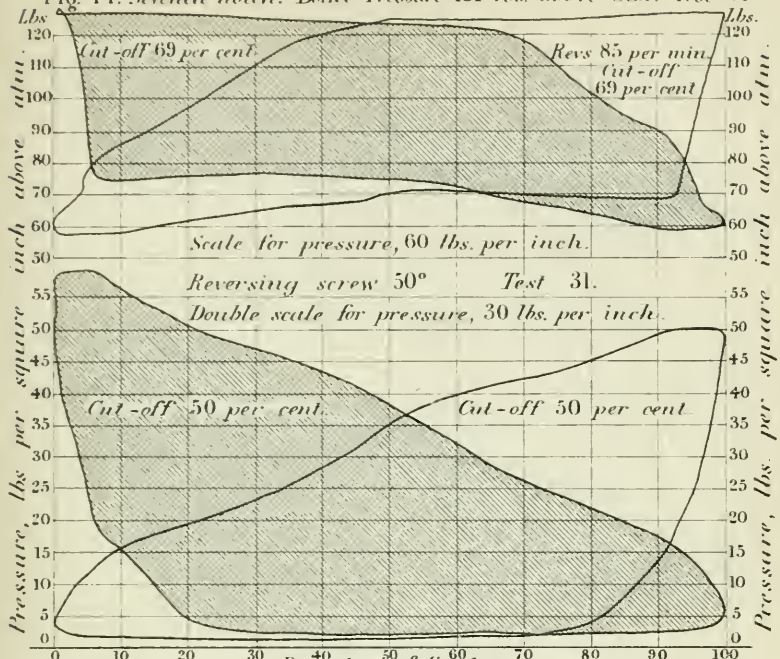
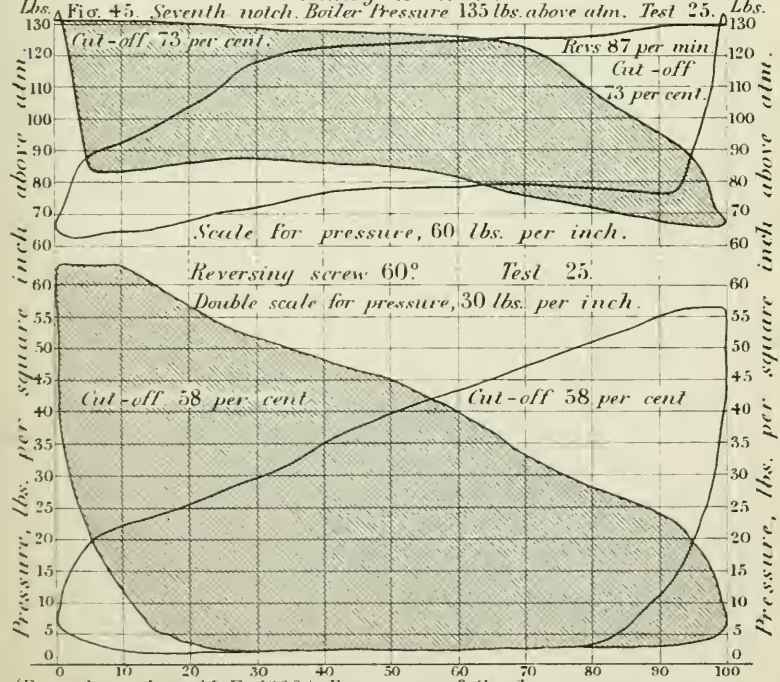


Fig. 45. *Seventh notch. Boiler Pressure* 135 *lbs. above atm. Test* 25.

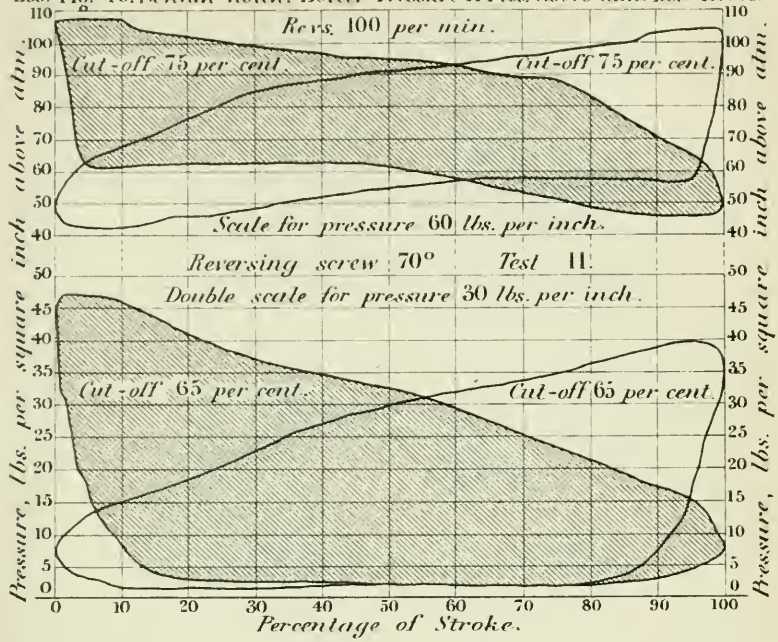


(*Proceedings Inst. M E. 1886.*)

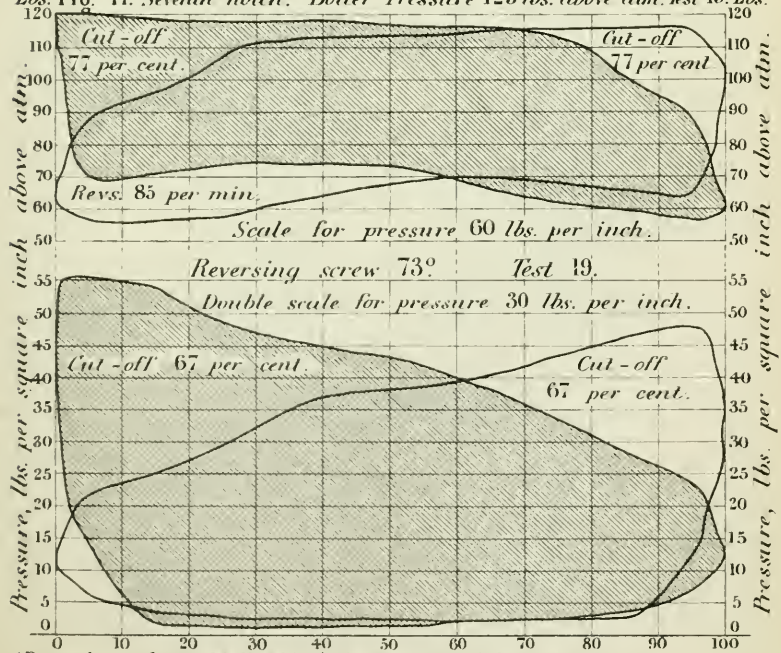
Indicator Diagrams from COMPOUND *Locomotive* A 7.

Jackets NOT *working.*

Lbs. Fig. 46. *Seventh notch. Boiler Pressure* 114 *lbs. above atm. Test* 11. *Lbs.*


Revs. 100 per min.
Cut-off 75 per cent.
Cut-off 75 per cent.
Scale for pressure 60 lbs. per inch.
Reversing screw 70° Test 11.
Double scale for pressure 30 lbs. per inch.
Cut-off 65 per cent.
Cut-off 65 per cent.
Pressure, lbs. per square inch above atm.
Percentage of Stroke.

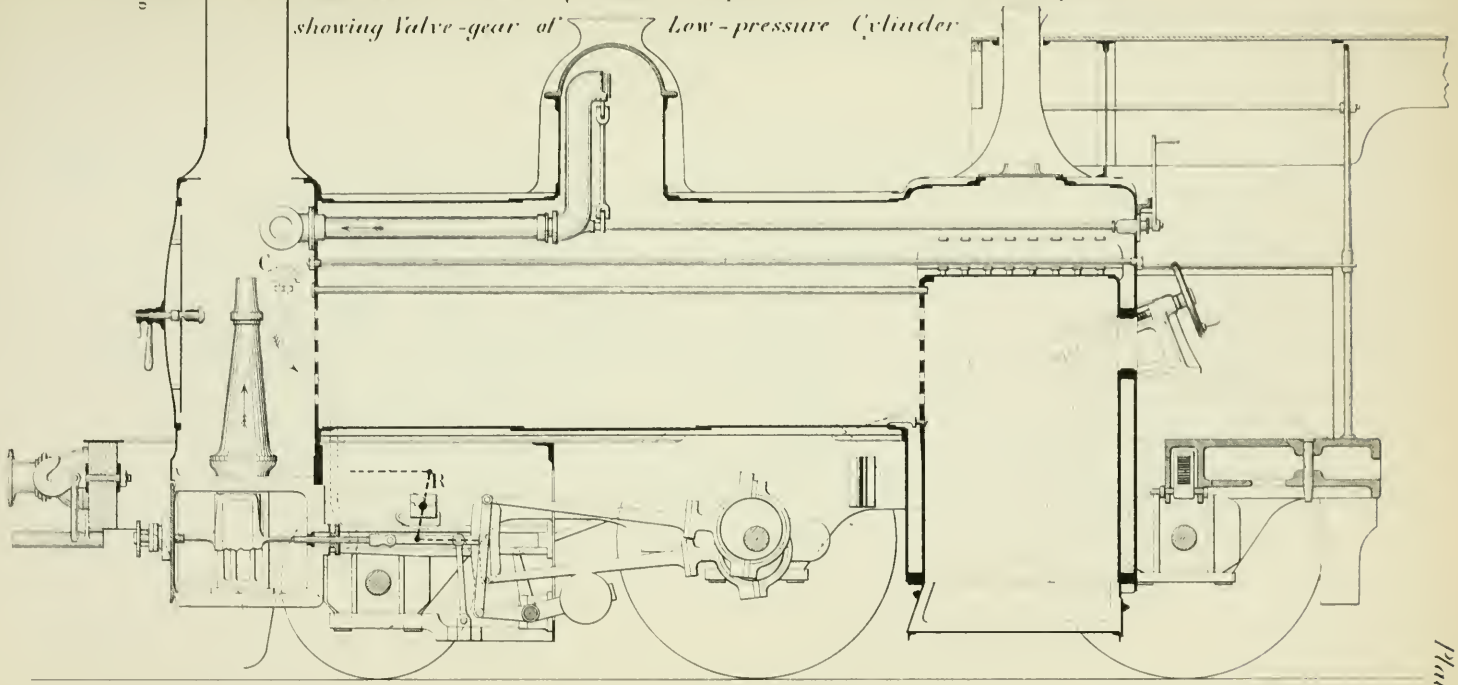
Lbs. Fig. 47. *Seventh notch. Boiler Pressure* 123 *lbs. above atm. Test* 19. *Lbs.*


Cut-off 77 per cent.
Cut-off 77 per cent
Revs. 85 per min.
Scale for pressure 60 lbs. per inch.
Reversing screw 73°. Test 19.
Double scale for pressure 30 lbs. per inch.
Cut-off 67 per cent.
Cut-off 67 per cent.
Pressure, lbs. per square inch above atm.
(Proceedings Inst. M.E. 1886.) Percentage of Stroke.

COMPOUND LOCOMOTIVES IN INDIA.

Fig 48

Elevation of Two-Cylinder Compound Locomotive "Vampire," showing Valve-gear of Low-pressure Cylinder



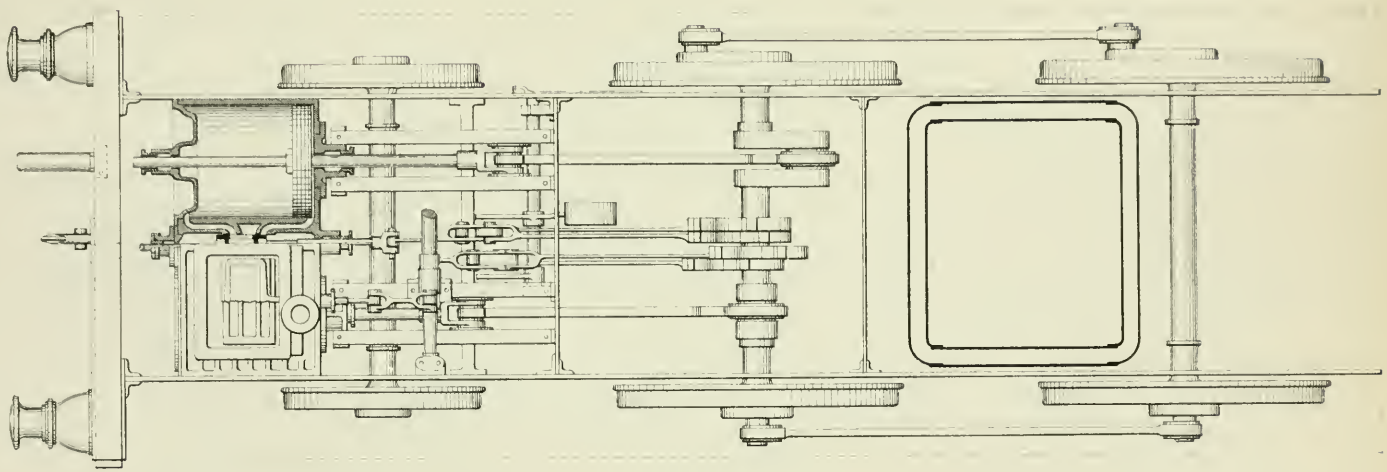
(Proceedings Inst. M. E. 1886.)

Scale $\frac{1}{40}$th

Ins 12 6 0 — 5 — 10 — 15 — 20 Feet

Plate 80.

Fig. 49. *Plan of Two-Cylinder Compound Locomotive "Vampire".*



(Proceedings Inst. M. E. 1886.)

Scale 1/40th

Ins. 12 6 0 5 10 15 20 Feet

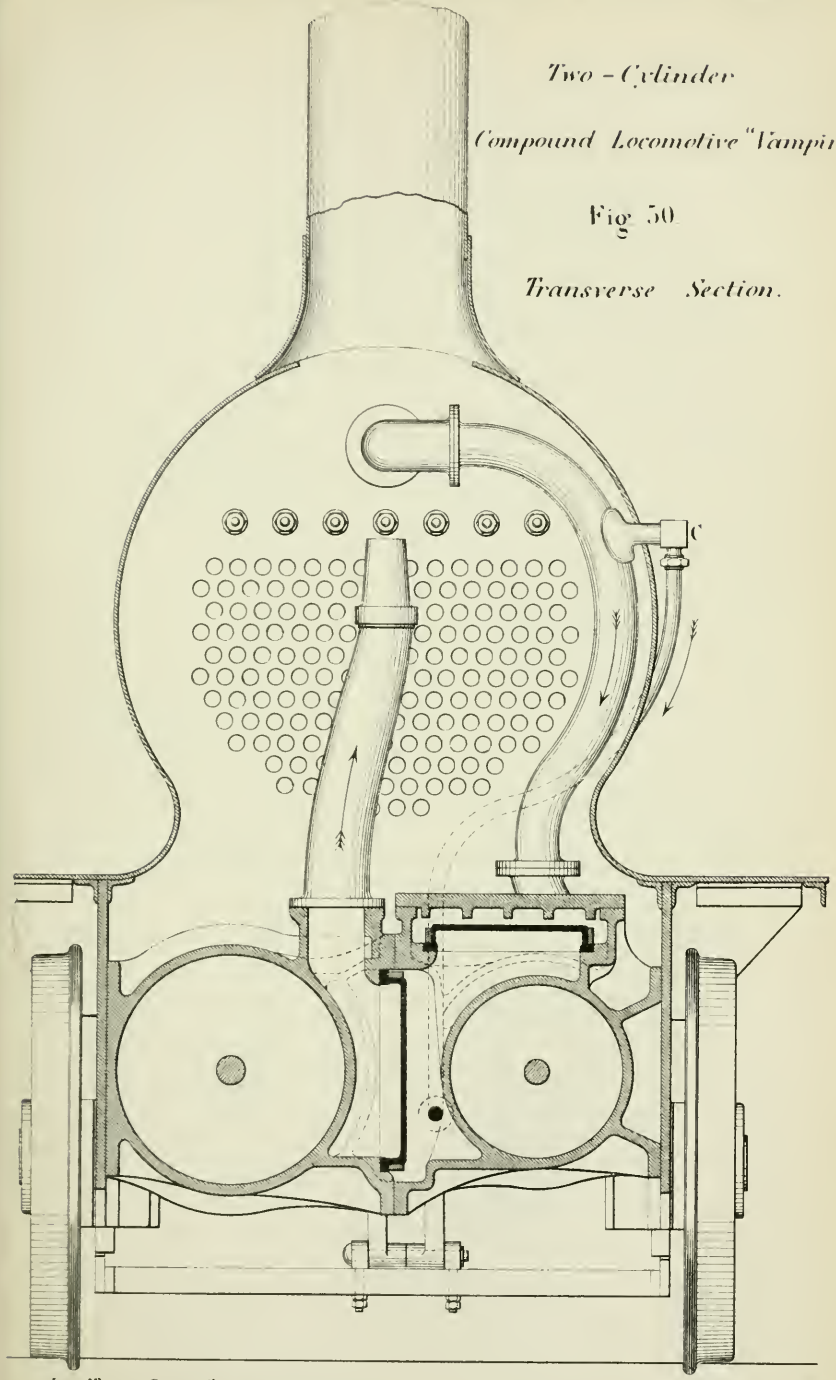
Plate 81.

Two-Cylinder

Compound Locomotive "Vampire".

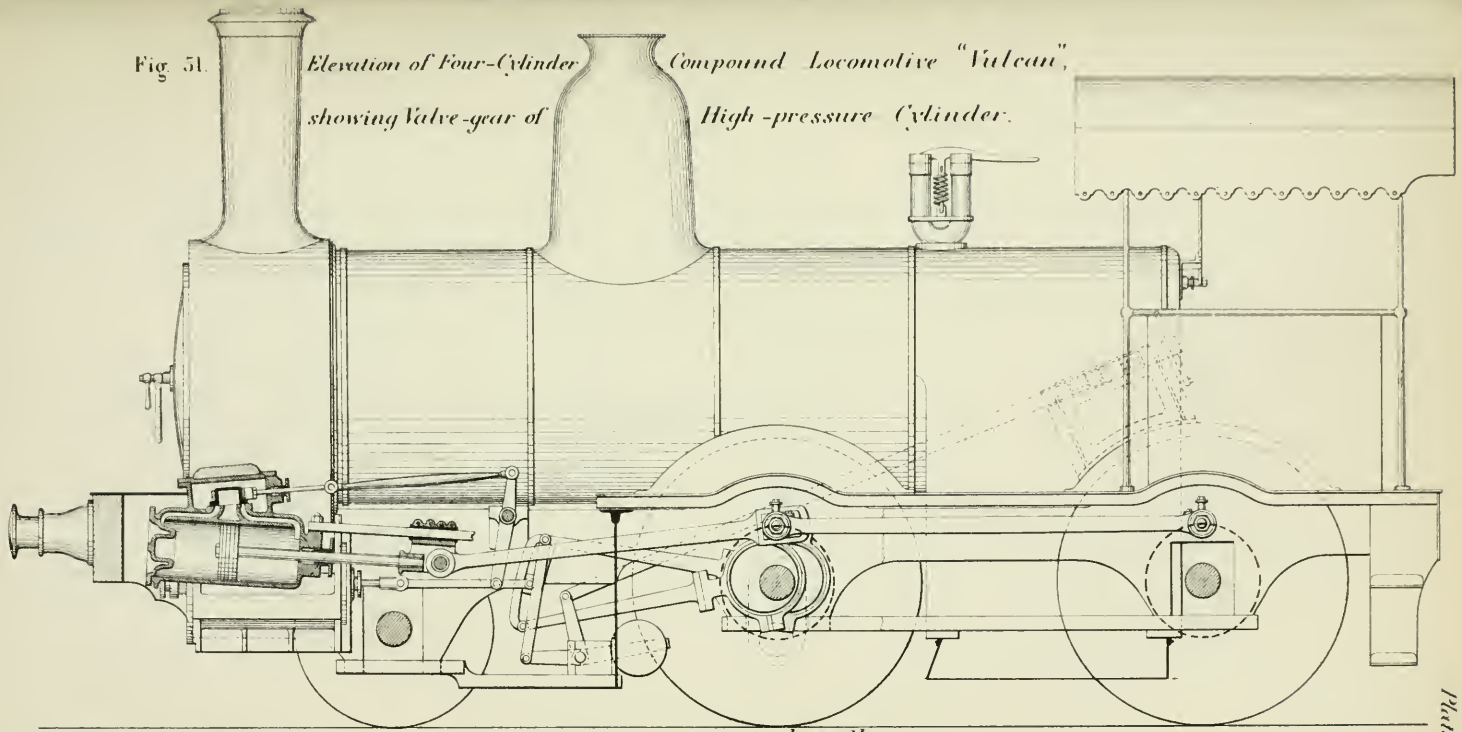
Fig. 50.

Transverse Section.



(Proceedings Inst. M. E. 1886.) *Scale* $\frac{1}{20}$*th*

Fig. 51. *Elevation of Four-Cylinder Compound Locomotive "Vulcan", showing Valve-gear of High-pressure Cylinder.*

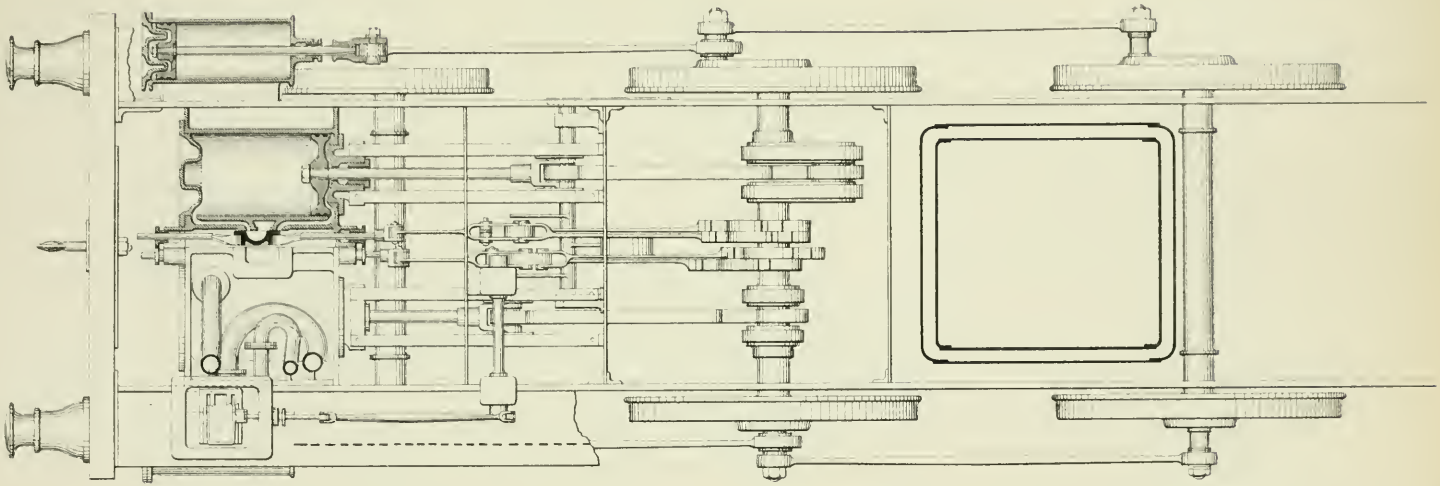


(Proceedings Inst. M. E. 1886.)

Scale $\frac{1}{40}$th

Ins. 12 6 0 5 10 15 20 Feet.

Fig. 52. *Plan of Four-Cylinder Compound Locomotive "Vulcan"*



(Proceedings Inst. M. E. 1886.)

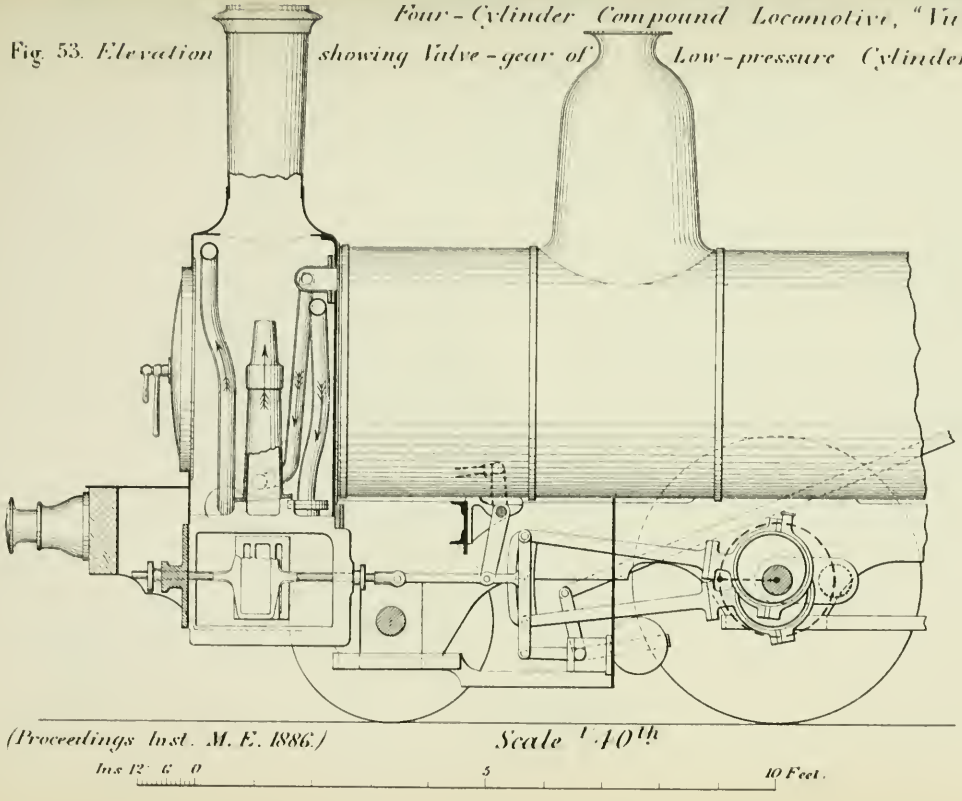
Scale $\frac{1}{40}$ th

Ins. 12 6 0 5 10 15 20 Feet

Plate 84.

Four-Cylinder Compound Locomotive, "Vulcan."

Fig. 53. *Elevation showing Valve-gear of Low-pressure Cylinder.*



(Proceedings Inst. M. E. 1886.) *Scale 1/40th*

Ins 12 6 0 5 10 Feet.

Fig. 54.

Plan of Pipes in Smoke-box.

Scale 1/20th

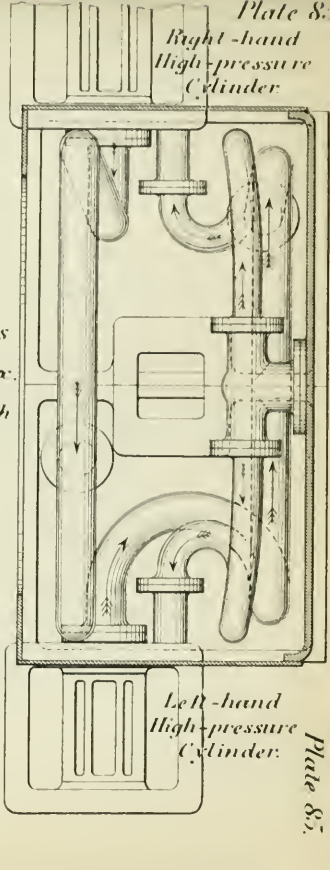


Plate 8.

Right-hand High-pressure Cylinder.

Left-hand High-pressure Cylinder.

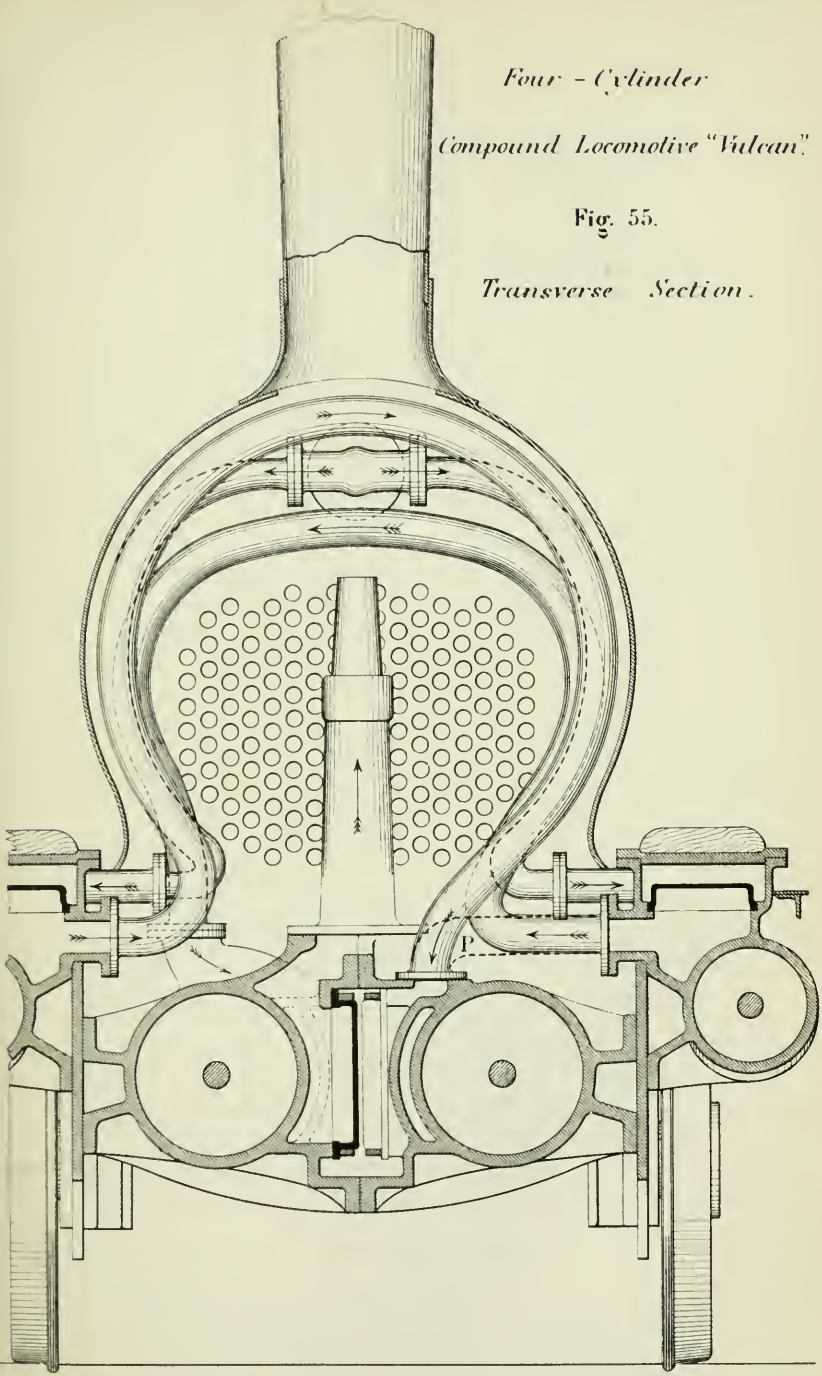
Plate 85.

Four - Cylinder

Compound Locomotive "Vulcan".

Fig. 55.

Transverse Section.



(Proceedings Inst. M. E. 1886.) *Scale 1/20th*

Fig. 56. *Friction Brake cooled by Water.*

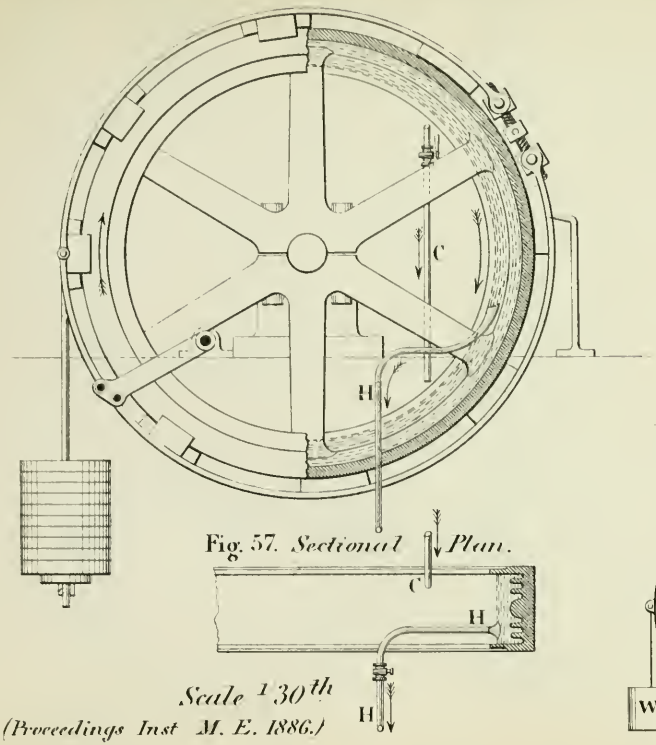


Fig. 57. *Sectional Plan.*

Scale 1/30th

(Proceedings Inst. M. E. 1886.)

Fig. 58. *Counterweighted Friction Brake.*

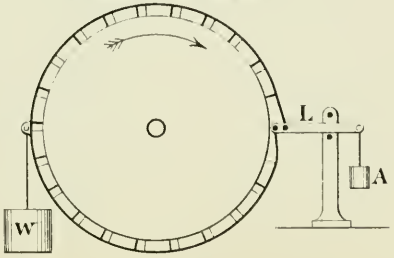


Fig. 59. *Draining of Steam-Jackets by Auxiliary Injector.*

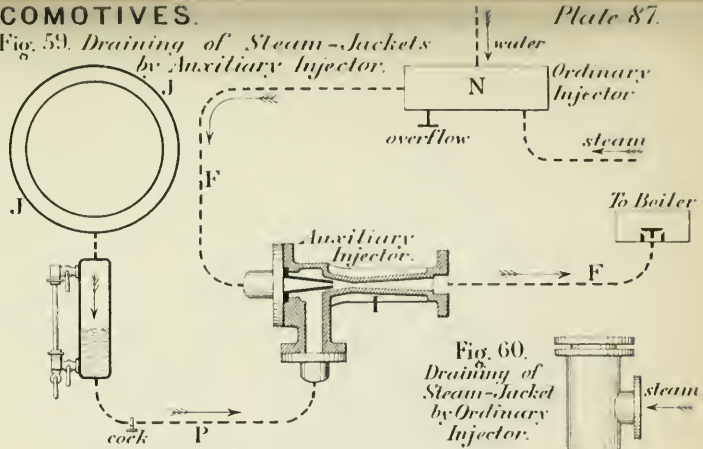


Fig. 60. *Draining of Steam-Jacket by Ordinary Injector.*

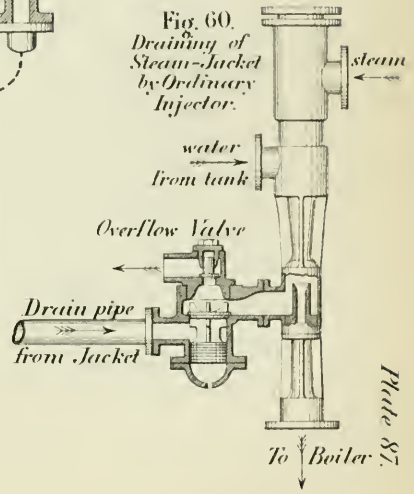


Fig. 61. *Indicator Diagrams showing effect of long and short indicator pipes.*

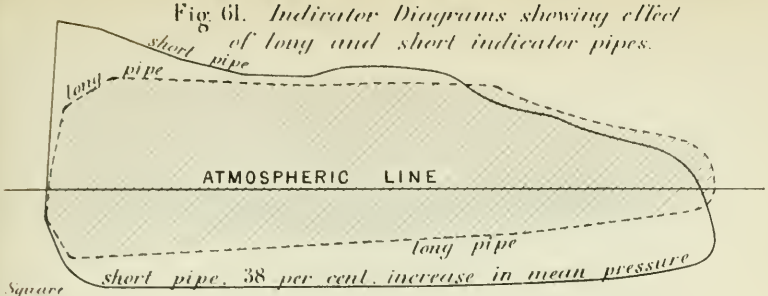


Fig. 62. *Area of Jacket-Surface per cubic foot of Cylinder Volume.*

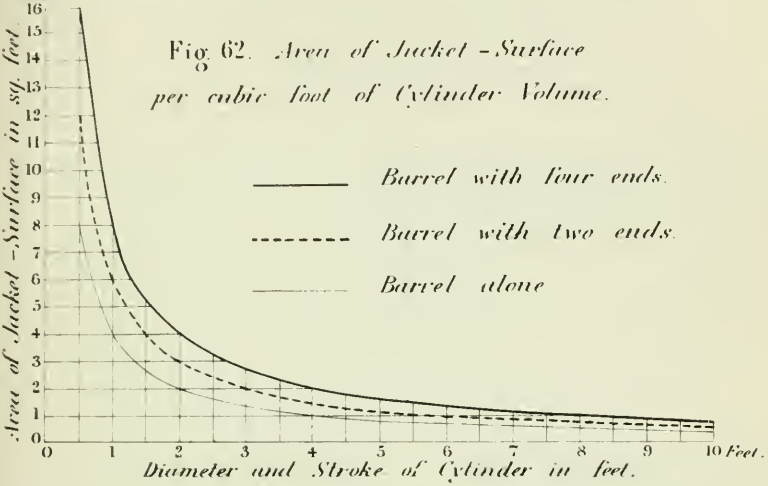
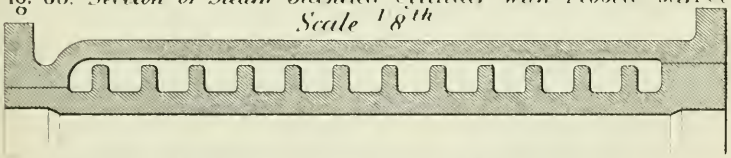
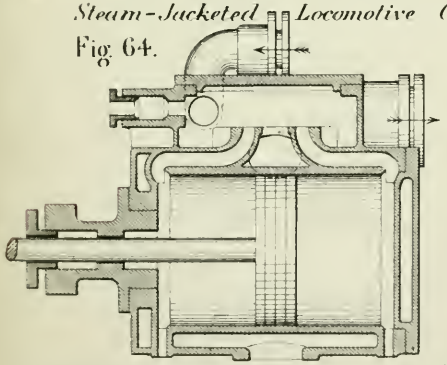


Fig. 63. *Section of Steam-Jacketed Cylinder with ribbed barrel.*
Scale 1/8th



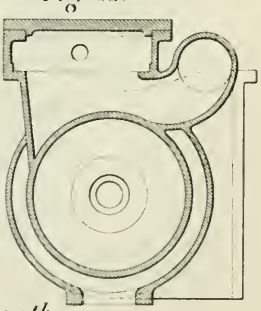
Steam-Jacketed Locomotive Cylinder, 1857.

Fig. 64.



(Proceedings Inst. M.E. 1886.)

Fig. 65.



Scale 1/20th

Institution of Mechanical Engineers.

PROCEEDINGS.

October 1886.

The Autumn Meeting of the Institution was held in the Yorkshire College, Leeds, on Monday, the 18th of October 1886, by invitation of the College Authorities, in celebration of the opening of the Engineering Department of the College.

The chair was taken at Half-past Three o'clock p.m. in the Lecture Theatre by the President, Jeremiah Head, Esq.

The Minutes of the previous Meeting were read, approved, and signed by the President.

The President announced that the Ballot Lists for the election of New Members had been opened by a committee of the Council, and the following twenty-three candidates were found to be duly elected:—

MEMBERS.

Alfred Julius Boult, . .	London.
William Bright, . . .	Pontardulais.
Edmund Barrow Chittenden, .	Sittingbourne.
Samuel Clayton, . . .	Bradford.
Charles David Doxford, . .	Sunderland.
William Mayhew Folger, . .	Fitchburg, U.S.
Charles Walker Hilton, . .	Nottingham.
James Holden, ...	London.
William Johnson, . . .	London.
Albert Ebenezer Schurr, . .	London.
James Bradford Trew, . .	Swansea.
Edwin Wells Windsor, . .	Rouen.

ASSOCIATES.

Keith Ronald Mackenzie, .	Henley.
Henry Edward Newton, .	London.
Henry Baldwin Raven, .	London.
Frederick Stumore, . .	London.

GRADUATES.

Thomas Johnstone Bourne,	Bolton.
Frederick Evelyn Cairnes,	London.
Charles Anthony Duvall, .	London.
Francis Matthew Holdsworth,	Birmingham.
William Thomas Lewis, Jun.,	Cardiff.
Alvaro Gomes de Mattos, .	London.
Seymour William Price-Williams,	London.

The President announced that, in accordance with the Rules of the Institution, the President, two Vice-Presidents, and five Members of Council, would retire at the ensuing Annual General Meeting; and that the list of those retiring was as follows:—

PRESIDENT.

Jeremiah Head, ...	Middlesbrough.

VICE-PRESIDENTS.

Charles Cochrane, ...	Stourbridge.
Richard Peacock, M.P., . . .	Manchester.

MEMBERS OF COUNCIL.

Samuel W. Johnson, . . .	Derby.
Edward P. Martin, . . .	Dowlais.
Arthur Paget, ...	Loughborough.
R. Price-Williams, ...	London.
Sir James Ramsden, . . .	Barrow-in-Furness.

The following was the list of those retiring who had been nominated by the Council for re-election :—

VICE-PRESIDENTS.

Charles Cochrane, ...	Stourbridge.
Richard Peacock, M.P., . . .	Manchester.

MEMBERS OF COUNCIL.

Samuel W. Johnson, . . .	Derby.
Edward P. Martin, ...	Dowlais.
R. Price-Williams, ...	London.
Sir James Ramsden, . . .	Barrow-in-Furness.

The following nominations had also been made by the Council for the election at the Annual General Meeting :—

PRESIDENT.

E. H. Carbutt, ...	London.

VICE-PRESIDENT.

Arthur Paget, ...	Loughborough.

MEMBERS OF COUNCIL.

Election as Member.		
1856.	William Anderson, . . .	London.
1869.	Arthur Keen, ...	Birmingham.
1871.	James Platt, ...	Gloucester.
1872.	William Laird, . . .	Birkenhead.
1873.	John G. Mair, ...	London.
1874.	Dr. John Hopkinson, F.R.S., .	London.

The President reminded the Meeting that according to the Rules of the Institution any Member was now entitled to add to the list of candidates.

No other names were added.

The President announced that the foregoing names would accordingly constitute the nomination list for the election of officers at the Annual General Meeting.

The following Paper was then read and partly discussed :—

On Triple-Expansion Marine Engines; by the late Mr. Robert Wyllie, of Hartlepool.

At Six o'clock the discussion, not being concluded, was adjourned to the next Meeting.

The Most Honourable the Marquis of Ripon, K.G., President of the Yorkshire College, then entered the Lecture Theatre, accompanied by a deputation of the Council, Engineering Committee, and Senate of the College, including Sir Edward Baines, Sir Andrew Fairbairn, Mr. John Barran, M.P., Mr. John Marshall, Principal Bodington, &c.

The Marquis of Ripon, K.G., said he was present as the President of the Yorkshire College, accompanied by his colleagues on the Council and the professors of the College, for the purpose in the first place of offering a hearty welcome to the Institution of Mechanical Engineers on the occasion of this their meeting in Leeds, held in the College in accordance with the invitation to that effect which they had accepted. In the next place he had come to ask the President and the Members of the Institution to accompany him round the new building connected with the Engineering Department, and to declare this new building open. Those who had had the management of the Yorkshire College from its commencement had always been very sensible of the great importance, in a district such as this, of the engineering department of the College ; and as time had gone on, as the funds had increased, and as the scope of their operations had been extended, he trusted they had not been forgetful of the duties which lay upon them in that respect; and it had been their constant effort to render the engineering department as complete and perfect as they could. With that view, the College had a short time ago invited the leading engineers of the district to form themselves into a Committee, in order to consider and inform the Council of the College by what means the engineering department could be rendered more efficient.

It was upon their report that the College determined to make an effort to raise a sum of £10,000, and to erect the building which the President was now about to open. A description of the building, and of the machines and appliances with which it was provided, had been furnished to the Members of the Institution, whom he now invited to verify it by their own inspection. He trusted they would find that the whole of the arrangements were suitable for the purpose in view, and were calculated to afford a solid and thorough instruction in engineering. The building itself had been completed some little time ago, and had been already in use; but the machines and appliances having only just been placed therein, it had been determined to postpone the formal opening of the building until the present meeting of the Institution, because it was felt that it would be a very great advantage to the College if this opportunity could be taken for interesting the Institution in the work which was being done here, and if the College could be so fortunate as to secure the approval of the Members for the result of the efforts thus far made. He now asked the President and the Members to accompany himself and his colleagues round the building; and if what they here saw should meet with their approval, it would be a source of great satisfaction and strength to the College.

The President thanked the noble Marquis and the Council of the College, on behalf of the Institution of Mechanical Engineers, of which he had the honour to be President, for the very warm welcome which they had given to the Institution, and for the characteristically kind words in which his lordship had conveyed that welcome. It had been their custom to hold their autumn meeting in some large mechanical centre. The invitation to meet in Leeds on the present occasion had been gladly accepted: firstly, because they knew that here they should be among all those mechanical arts in which they were most particularly interested; secondly, because they were certain to meet many warm friends, for many of their most active members were Leeds engineers; and thirdly, because they were given to understand that their meeting might be of some service in making known the splendid efforts which the College had put forth

(The President.)

to promote the cause of technical education. His lordship however had made one slight mistake in his remarks. He had spoken as though the Institution were doing the College a favour in holding their autumn meeting here. But he was quite sure that all the Members would agree with him when he said that the College could not be half so pleased to see them as they were to come. In order that all might be enabled to take the greatest advantage of the limited time available for the inspection of the building and its contents, he would proceed at once to perform the duty with which he was charged. He therefore declared the Mechanical Department of the Yorkshire College open now and henceforth. He confidently trusted that it would prove in the future as valuable an institution as it promised to be, and as its founders seemed determined to make it.

The President and Members then accompanied the Marquis into the mechanical laboratory, where the 100-ton single-lever testing machine was put into operation by the President, and the two-cylinder horizontal engine, specially designed with a view to experimental purposes, was seen at work. These were minutely inspected, as was also the rest of the machinery and appliances throughout the mechanical department.

The Meeting then terminated. The attendance was 120 Members and 78 Visitors.

In the evening the President and Council and the Members of the Institution were invited to Dinner in the Victoria Hall, Town Hall, by the Engineers of Leeds and district. The chair was occupied by the Most Honourable the Marquis of Ripon, K.G., President of the Yorkshire College, who was supported by the Mayor of Leeds (Alderman Gaunt), and the President of the Institution; Mr. Thomas Hawksley, F.R.S., Past-President; Mr. Daniel Adamson, Mr. E. H. Carbutt (President elect), Mr. Charles Cochrane, Mr. David Greig, and Mr. Joseph Tomlinson, Vice-Presidents; Sir James N. Douglass,

Professor Alexander B. W. Kennedy, Mr. Edward B. Marten (Stourbridge), Mr. Arthur Paget, Mr. E. Windsor Richards, Mr. Benjamin Walker, Mr. J. Hartley Wicksteed, and Mr. Thomas W. Worsdell, Members of Council; Mr. Edward Woods, President of the Institution of Civil Engineers; Sir Andrew Fairbairn, Chairman of the Engineering Committee of the Yorkshire College; Sir James Kitson, Bart., Mr. John W. Naylor, and Mr. T. A. O. Taylor, Governors of the College; Mr. John Marshall, Chairman of the College Council; Mr. John Barran, M.P., Mr. Henry Davey, Mr. Obadiah Nussey, the Hon. R. C. Parsons, Mr. Richard Reynolds, Mr. Walter Rowley, Mr. Thomas Scattergood, and Mr. Frank N. Wardell, Members of the College Council; Mr. Joshua Buckton, Mr. Arthur T. Lawson, Mr. Alexander S. Macpherson, and Mr. A. H. Meysey-Thompson, Members of the Engineering Committee; Principal Bodington, and other Members of the College Senate; Professor James Thomson, Glasgow University; Dr. Garnett, Principal of the Durham College of Science; Sir George Morrison, Town Clerk; and the Rev. F. J. Jayne, Vicar of Leeds.

After the usual loyal toasts, the Marquis of Ripon proposed the toast of "The Institution of Mechanical Engineers," which was acknowledged by the President, by Mr. Thomas Hawksley, F.R.S., Past-President, and by Mr. E. H. Carbutt, Vice-President. "The Institution of Civil Engineers" was proposed by Sir James Kitson, Bart., and acknowledged by the President, Mr. Edward Woods. "The Engineering Department of the Yorkshire College," proposed by the President of the Institution of Mechanical Engineers, was acknowledged by Sir Andrew Fairbairn, Chairman of the Engineering Committee, and the Hon. R. C. Parsons, Member of Council of the College. The toast of "The Other Departments of the Yorkshire College" was proposed by Mr. Benjamin Walker, and acknowledged by Mr. John Marshall, Chairman of Council of the College. "The Town, Trade, and Professions of Leeds," proposed by Mr. Daniel Adamson, was acknowledged by the Mayor, by Mr. John Barran, M.P., and by the Rev. F. J. Jayne, Vicar of Leeds. "The Chairman," as the concluding toast, was proposed by Mr. David Greig, and acknowledged by the Marquis of Ripon.

A donation of Two Hundred and Fifty Guineas to the Engineering Department of the Yorkshire College, from Messrs. T. and C. Hawksley, was presented by Mr. Thomas Hawksley, F.R.S., Past-President of the Institution.

ON TRIPLE-EXPANSION MARINE ENGINES.

By the late Mr. ROBERT WYLLIE, of Hartlepool.

The last few years may be regarded as a transition period in the history of Marine Engineering, as the high-pressure Triple-Expansion Engine has now proved the successful rival of the double-expansion compound. The object of the present paper is to bring forward the results of experience with this new type of engine, and to consider briefly the various points which have a direct bearing on its efficiency, as well as the most suitable design for marine purposes.

Position of Cylinders.—There has been great difference of opinion regarding the best method of placing the three cylinders in a triple-expansion engine of ordinary size; and some very crude plans have been adopted since the introduction of the system by Mr. A. C. Kirk in the "Propontis." The high-pressure cylinder placed on the top of either the intermediate-pressure or the low-pressure has been tried, together with many schemes to lessen the difficulties of overhauling: whilst the main objections to this design appear to have been overlooked. With the exception of what was being done in the matter by Mr. Kirk, no further attempt seems to have been made to construct small-power triple-expansion engines on three cranks until about three years ago, when the writer undertook to build one of 700 I.H.P. which should fulfil the condition that no more space was to be occupied than would have been taken up with an

ordinary compound. Engines of small power had previously been constructed on the tandem principle; but experience had shown the writer that, in order to take full advantage of the triple-expansion system, an engine must be built on three cranks placed at equal angles; and the best proof that this was the correct solution of the problem is the fact that the arrangement is now almost universally followed, although at the time it was considered by the advocates of the tandem engine and others to be a step entirely in the wrong direction.

General Conditions of Efficiency.—The most important conditions to be considered in order to obtain an efficient engine, are that there should be approximate equality—firstly in the range of temperature in each cylinder; secondly in the initial stress on each crank; and thirdly in the indicated horse-power of each cylinder. With a view to the practical realisation of these three essentials, the principal elements which have to be considered in the construction of the engine are:—(1) steam-jacketing of cylinders; (2) cylinder ratios; (3) velocities of initial and exhaust steam; (4) clearance and compression; (5) receiver capacity; (6) piston speed; (7) order of sequence of cranks.

Steam-Jackets.—The subject of steam-jacketing, and of fitting cylinders with working barrels cast separately, has undergone considerable discussion amongst engineers, although the theoretical advantages of the system have long since been admitted. Keen competition seems evidently to have been one of the reasons why this fitting has in many instances been discontinued, in order to meet the demand for a cheap engine. Thorough investigation of the subject is beyond the scope of this paper; but the action of the cylinder surface, producing as it does an influence on coal consumption, deserves more attention than it often receives. In a single-cylinder engine with a high ratio of expansion and a large range of temperature, it is well known that in each stroke there is excessive initial condensation, followed by partial re-evaporation.

In triple-expansion engines, where attention is paid to the equal division of the total range of temperature amongst the cylinders in which the successive stages of expansion take place, the benefits arising from the use of jackets are naturally not so great as in a single-cylinder engine with a high ratio of expansion; but however carefully the triple engine may be designed, the jacketing of at least the intermediate and low-pressure cylinders is essential to maximum efficiency.

Beyond the actual economy resulting from steam-jacketing, there are numerous practical advantages of a working barrel cast separately. The cylinder barrel being one of the most vital parts of an engine, it is essential that it should be of the finest material and of uniform quality, in order to prevent it from wearing unevenly, as an oval or uneven cylinder means a leaky piston and increased coal consumption. In the case of a cracked cylinder without an independent liner, the expense of renewal is very great, whilst a new liner costs but little; and the additional facility given for heating up cylinders fitted with independent liners, by admission of steam into the jacket space, is a safeguard against accidents of that description.

Cylinder Ratios.—The ratio of cylinder capacities in a triple-expansion engine depends on the pressure of steam and the type of engine. In cargo steamers, where economy of fuel is of vital importance and a large range of reserve power is not necessary, the high-pressure cylinder should be of such a diameter that with a cut-off at from 50 to 60 per cent. the theoretical absolute terminal pressure in the low-pressure cylinder shall not exceed 10 lbs. per square inch. In war-ships, where a large range of power is sometimes required and economy of fuel is not so important, the high-pressure cylinder should be larger in proportion, so that a higher mean pressure can be obtained. In triple-expansion engines on three cranks, the intermediate cylinder should be so proportioned that, with 55 to 65 per cent. cut-off, the powers, the ranges of temperature, and the initial stresses in the three cylinders may approach equality.

Steam Velocities.—To obtain even approximate equality in powers, temperatures, and stresses, requires the greatest care in designing the steam passages throughout the engine; and unless the velocities of the steam at the various points, and the degrees of cut-off by the valves, are carefully proportioned, it will be found that these three elements of economy and of efficient working are very far from being realised. The greater number of published results show that the subject is still inadequately appreciated. In Fig. 7, Plate 93, is shown a high-pressure diagram taken from an engine with 135 lbs. boiler-pressure, and drawn out in the manner described in the memorandum appended (page 490). The velocity in the passages was by no means high, but the pipes were indirect, and owing to specified requirements there were several altogether unnecessary valves; the result was a fall of pressure to 120 lbs., or a loss of 15 lbs. available initial pressure. When the objectionable bends were removed, the initial pressure in the diagram rose to 130 lbs., as shown in Fig. 8, thus raising the ratio of expansion and increasing the general efficiency. The stroke of the engine was 3 feet, and the revolutions 104 per minute. Fig. 9, Plate 93, is a high-pressure diagram from a cylinder of the same diameter and stroke, the revolutions being 70 per minute. With 145 lbs. boiler-pressure, the initial pressure is here 140 lbs. This shows how small the initial drop may be, when the sources of loss are thoroughly appreciated.

Piston Valves.—The use of piston-valves on the intermediate and low-pressure cylinders, especially in engines of moderate power, serves to illustrate how the indirectness of the valve passages impairs the efficiency of the steam, and in some cases more than balances the beneficial effect of reduced friction in the machinery. Fig. 11, Plate 94, is a diagram taken from the intermediate cylinder of a triple engine fitted with a piston-valve, and shows considerable wire-drawing, which is to be attributed to the indirectness of the valve passages; for in Fig. 12, taken from a similar engine in every respect, with only a slightly lower speed of steam, but fitted with an ordinary slide, it is seen that the wire-drawing is much less.

Low-pressure Cylinder.—The low-pressure cylinder is of course the source of the greatest inefficiency; and too much care cannot be taken in the design of the steam and exhaust passages. The steam passages should be as small in capacity as possible, so as to reduce the clearance to a minimum; yet the speed of the entering steam should not be so high as to cause excessive frictional resistance, nor the speed of exhaust so high as to augment the back pressure; consequently the greatest efficiency is obtained when the revolutions and indicated horse-power are not required to vary to any great extent. As an illustration, Fig. 15, Plate 96, is a diagram taken from a low-pressure cylinder which was designed for 60 to 65 revolutions per minute: on the light-ship trial the engines were run at 78 revolutions, and as shown in Fig. 16 the vacuum was then $1\frac{3}{4}$ lbs. less than with the same cut-off at 68 revolutions, the loss being entirely due to the excessive exhaust velocity consequent on driving the engines at a greater speed than they were designed for.

Contracted or indirect exhaust passages in the high-pressure and intermediate cylinders have the effect of causing a larger difference between the back pressure on one piston and the initial pressure on the next, thus diminishing the efficiency of the steam. An illustration of this defect is furnished by the diagrams shown in Fig. 17, Plate 96; these were taken from a triple-expansion engine built in the north of England, of which the following are particulars:—

	High.	Intermediate.	Low.
Indicated Horse-power, 894 total	267·9	282·5	343·6
Initial Stress, lbs.	34976	47623	60605
Range of Temperature, Fahr.	63°	67°	100°

Sequence of Cranks—high, low, intermediate.

Cut-Off.—The cut-off necessary to maintain the equality of the three essentials for an efficient engine is governed to a great extent by the speed of the entering steam and the nature of the passages, inasmuch as the same amount of steam per stroke may enter the cylinder at the ordinary working number of revolutions per minute, as at a higher speed with later cut-off and larger

port-opening; and in the latter case the difference will be greater between the actual and the effective cut-off. Fig. 10, Plate 93, is a high-pressure diagram taken on a light-ship trial, and shows the effect produced by a high velocity of steam on the volume admitted at each stroke, the actual cut-off in this case being 8 per cent. later in the stroke than the virtual or effective cut-off. In the intermediate and low-pressure cylinders too high a velocity of the entering steam will produce excessive frictional resistance, causing a drop in the expansion curve as well as an unduly high receiver pressure, thus disturbing the equality of temperatures and of initial stresses. Fig. 13, Plate 95, is a diagram taken from the intermediate cylinder on a light-ship trial with a high steam velocity through the ports, whilst Fig. 14 is a diagram from the same cylinder in the loaded ship; the cut-off was equal in both instances, yet in the latter case the receiver pressure is 7 lbs. lower, and the drop in the expansion curve is very considerably reduced.

A three-crank engine, with its more uniform twisting moment on the shaft, and its approximately equal initial loads, presents every facility for increased revolutions or higher piston-speed; and as lighter machinery for the same power developed admits of additional capacity for carrying cargo, the recognised standard of sixty revolutions per minute, so indelibly stamped on marine engineering practice, is unfavourable to the greatest economy. It is true that the absurdly bluff run aft, which is found in many steamers, interferes with a high number of revolutions; but there is no reason why a considerable advance should not be made. Engineers are often severely handicapped and sometimes utterly baffled by the design of the cargo "receptacle" which has to be propelled; and should the speed not reach the unreasonable expectations formed, the general inefficiency of the engines is at once set down as the cause, although the ship may have a displacement coefficient as high as 77 per cent., and may never run a straight course except by accident. That ships having a large cargo-carrying capacity and travelling at a low speed are pecuniarily successful is not to be denied; but that

beneficial results would follow from a slightly less box-like form is abundantly evident, though not yet universally appreciated in practice.

Sequence of Cranks.—In a triple engine some diversity of opinion seems to have existed as to the order of sequence for the three cranks. Many engines are arranged with the high-pressure crank leading, followed by the intermediate crank, and the low-pressure crank last: which causes excessive variation in the receiver pressure, increased ranges of temperature in the cylinders, and considerable differences in initial stresses. The better sequence is high-pressure leading, low-pressure following, and intermediate last. Combined diagrams are shown in Fig. 18, Plate 97, from an engine built on the Tyne with the common arrangement of cranks, namely—high, intermediate, and low; here the pressure in the receiver into which the high-pressure cylinder exhausts is seen to vary as much as 22½ lbs., this large amount being probably due to the receiver being too small. The temperatures and stresses in the high-pressure and intermediate cylinders approach equality; but the amount in each case is much greater than it would have been, had the low-pressure crank followed the high-pressure. The following are particulars:—

Screw Steamer "Hispania"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	20	31	52
Length of Stroke, inches	36	36	36
Revolutions per minute	68·93	68·93	68·93
Indicated Horse-power, 613 total	214	205	194
Initial Stress, lbs.	30938	35098	31855
Range of Temperature, Fahr.	76·2°	78°	80·8°

Sequence of Cranks—high, intermediate, low.

The diagrams in Figs. 21 and 22, Plate 98, are from an engine built in Scotland with the same sequence of cranks as in Fig. 18, namely high, intermediate, and low; but the receiver from the high-pressure cylinder being here larger, the variation of pressure in it is reduced to 12 lbs. In this engine however the temperatures and stresses are astray, the effects of the latter being shown in the crank-

shaft diagram, Fig. 22, which is constructed in the manner described in the memorandum appended (page 491). The following are particulars:—

	High.	Intermediate.	Low.
Indicated Horse-power, 2000 total	618	615	767
Initial Stress, lbs.	57868	68979	75045
Range of Temperature, Fahr.	72·3°	67·2°	83·6°

Sequence of Cranks—high, intermediate, low.

Crank-shaft Stresses: maximum 118, mean 100, minimum 69·4.

In Figs. 23 and 24, Plate 99, the low-pressure cylinder follows the high-pressure, with the evident beneficial effect of reducing the variation of pressure in the first receiver to 6 lbs., and also reducing the ranges of temperature in the cylinders, as well as the initial loads on the pistons, and the variations in the crank-shaft stresses, Fig. 24. The following are particulars:—

Screw Steamer "Shakespear"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	21	34½	55½
Length of Stroke, inches	36	36	36
Revolutions per minute	65·8	65·8	65·8
Indicated Horse-power, 871 total	297	287	287
Initial Stress, lbs.	34000	35232	35078
Range of Temperature, Fahr.	73°	71°	73°

Sequence of Cranks—high, low, intermediate.

Crank-shaft Stresses: maximum 117, mean 100, minimum 78·7.

Number of Cranks.—The question of the most suitable type of marine engine resolves itself into two general divisions, namely—engines working on two cranks, and those working on three. Considerable difference of opinion has existed as to which is the better, and many engineers have decided in favour of the two-crank tandem, the high-pressure cylinder being placed over either the intermediate or the low-pressure. A preferable arrangement is to place two cylinders on each crank. But both these plans present very objectionable features. In a three-cylinder tandem it is impossible to obtain anything approaching equality of temperatures, stresses, and powers; and therefore the result is a loss of efficiency. In converting compounds into triple-expansion engines, the method

of adding another cylinder on the top of the high-pressure or low-pressure is certainly an easy way of applying the triple-expansion principle, but for obvious reasons it is a very objectionable one. The diagrams shown in Figs. 19 and 20, Plate 97, are from a tandem engine in which every possible care was taken in the design; yet the results do not compare at all favourably with those from a good three-crank engine, as in Figs. 23 and 24, Plate 99. The following are particulars :—

Three cylinders on two cranks	High.	Intermediate.	Low.
Indicated Horse-power, 307 total	110	126	71
Initial Stress, lbs.	14235	22862	9237
Range of Temperature, Fahr.	66·1°	92·8°	38·3°

High and Low cylinders on Forward crank, Intermediate on Aft crank.
Indicated Horse-power, 307 total; Forward crank 181, Aft crank 126.
Initial Stress, lbs.; Forward crank 23472, Aft crank 22862.
Crank-shaft Stresses: maximum 156·5, mean 100, minimum 60.

To have two cylinders on each crank is undoubtedly the best design for a two-crank engine on the triple-expansion principle, as it is then possible to get an approximately equal initial stress on each crank. This arrangement of course necessitates one of the three stages of expansion taking place in two cylinders, instead of in one. The diagrams given in Fig. 25, Plate 100, are from this type of engine, and show the range of temperature varying from 59° to 81°; whilst the crank-shaft diagram, Fig. 26, is even worse than that from an ordinary compound on two cranks. The following are particulars :—

Four cylinders on two cranks	High.	Intermediate.	Low.
Range of Temperature, Fahr.	81°	59·1°	78°

One Inter. cyl. above High on Forward crank, and one Inter. above Low on Aft.
Indicated Horse-power, 1096 total; Forward crank 549, Aft crank 547.
Initial Stress, lbs.; Forward crank 62486, Aft crank 58471.
Crank-shaft Stresses: maximum 160·5, mean 100, minimum 65·2.

A marine engine should be so designed that any working part can be easily examined or removed; and this is impossible with a tandem engine. The arrangement of cylinders on three cranks

fulfils the required conditions more nearly than any other design; and that this is appreciated by many engineers and shipowners is evident from the rapidity with which the three-crank engines are entirely displacing the two-crank. A few of the principal advantages are:—(1) more uniform strain on shafting; (2) adaptability for a higher rate of revolution and increased piston-speed, thus obtaining increased efficiency from the steam in the engine, as well as lighter machinery in proportion to the power developed; (3) less wear and tear; (4) easier accessibility of working parts; (5) interchangeability of parts, thus minimising the consequences of a breakdown; (6) greater facility for repairs; (7) easier adjustment of temperatures, stresses, and powers. All these features are deserving of investigation.

Regarding the more uniform twisting moment on the crank shaft of a three-crank engine, it is often advanced that the difference between crank-shaft diagrams from a two-crank and a three-crank engine is not so great as to cause any appreciable effect. It must be remembered however that the variable twisting strains on the crank-shaft are reflected to a greater or less extent throughout all the working parts of the engine; and it seems certain that the beneficial influence of three cranks is far beyond what is generally accepted.

There seems to be an impression that the length of an engine-room is increased by the introduction of three cranks. But by placing the valve casings at the side, thus allowing the intermediate and low-pressure cylinder covers to be brought close together, the total length of a three-crank engine is made no greater than in nine-tenths of the existing compounds. In the Orient liner "Lusitania," since she has been converted to three cranks by the writer, the distance longitudinally over the cylinders is one foot shorter than before, and the indicated horse-power is 1000 greater (page 489).

Valve Gear.—The arrangements for working valves are becoming very extensive, and a review of the various devices which are employed to distribute the steam in modern engines would by itself occupy a very lengthy paper. The requirements of a good valve-gear are,

that it shall give at both ends of the cylinder an equal distribution of steam at all grades of expansion, with a minimum of working parts, and with no undue strains. The four principal methods adopted to work valves are:—firstly, by the single eccentric; secondly, by the double eccentric; thirdly, by taking the motion from the connecting-rod; and fourthly, by a compound motion derived from both the piston-rod and the connecting-rod. All four of these have their advantages and defects, and vary considerably in complexity and in multiplicity of parts.

The single-eccentric valve-gear, shown in Figs. 1 to 4, Plates 89 and 90, giving almost perfect steam distribution, having few working parts, and being independent of the connecting-rod or piston-rod, seems eminently suitable to fulfil all the desired conditions. Fig. 1, Plate 89, represents a sliding-block gear of this kind, which has given every satisfaction in actual working; it is also shown separately and to a larger scale in Fig. 5, Plate 91. The arrangement is such as to allow free access to all the working parts, whilst occupying a minimum of space. The end of the eccentric-rod E reciprocates on guide-bars G, which are inclined at various angles to suit the desired action of the valve. Motion is imparted to the valve-spindle V from an intermediate joint J in the eccentric-rod E, which moves in an approximately elliptic path. A slot S in the tail of the guide-bars admits of varying their inclination to different extents for a given movement of the reversing engine R, Fig. 1, thus altering independently the cut-off in each cylinder. The long leverage and easy motion reduce the wear and tear to a minimum, as results in actual practice have proved. An objectionable feature however in an engine fitted with this sliding-block gear is that the valves are at the front, over the starting platform; and the exhaust has to be led by a belt round the low-pressure cylinder to the condenser.

To overcome this objection of the sliding-block gear, the swinging-link gear shown in Fig. 4, Plate 90, was designed. This is also shown separately and to a larger scale in Fig. 6, Plate 92. The eccentric-rod E, as in the last case, is placed diagonally over the condenser, but is here guided in an arc of a circle, by suspending it by a

swinging link L centred on a pin P, which pin is adjustable by the reversing engine R into various positions for varying the grade of expansion either ahead or astern. The movements for working the valve are transmitted from a joint J at the end of the eccentric-rod E, by a compensating link C connecting the joint with one arm of an oblique lever B, of which the other arm is jointed to the valve-spindle V. The compensating link C is an essential and distinguishing feature of this gear; it is so placed and proportioned relatively to the other parts as to produce practically equal port-opening and cut-off at each end of the stroke. There is a quick and a slow movement of the valve at each end of its travel: the slow movement being at the maximum port-opening, and the quick movement at the cut-off. The lead is also constant at all grades of expansion.

Practical Results.—In Figs. 1 and 2, Plate 89, are represented the engines of the s.s. "Para," belonging to Messrs. Steel Young and Co., which made her maiden voyage to the River Plate about $3\frac{1}{2}$ years ago. The cylinders are 19 inches, 35 inches, and 53 inches diameter, with 33 inches stroke. These being the writer's first triple-expansion engines, special arrangements were made for ascertaining the actual coal consumption per indicated horse-power; and Table 1 appended (pages 492 to 496) is a log of the results obtained during a three days' trial between Liverpool and Madeira. Although, in order to get a correct estimate of an engine's performance, the quantity and temperature of the feed and circulating water ought of course to be considered, yet there are so many practical difficulties in the way of getting these particulars on board ship that it has been found impossible to obtain any reliable data on these points. This steamer still continues on the same run, averaging 9 knots an hour on $10\frac{1}{4}$ tons of coal per day; and has not yet cost anything beyond the usual overhaul for repairs. The great saving in coal consumption with the triple engines is apparent when comparison is made with two sister ships fitted with compound engines, the "Ingram" and the "Wandle," belonging to the same company, and

built by the same builders; the comparison is shown in Table 2, which gives the average working over a period of three years. The

TABLE 2.—*Comparative Results from three similar Steamers with Compound and with Triple-Expansion Engines.*

Name of Screw Steamer	Ingram	Wandle	Para
Length, feet and inches	257 6	257 6	257 6
Breadth, feet and inches	34 6	34 6	34 6
Draught, feet and inches	18 10½	18 6½	19 4
Dead Weight carried, tons	2310	2203	2398
Type of Engines	Compound	Compound	Triple
Boiler Pressure, lbs. per sq. inch	75	75	150
Speed, knots per hour	8½	8½	9
Indicated horse-power, total	570	580	620
Coal consumption per day, tons	13¾	14	10¼

diagrams in Fig. 35, Plate 105, are a combined set taken during the three days' trial of the "Para"; but owing to the intermediate cylinder being rather too large, the equalities of temperatures and of initial stresses are disturbed; and the drop of the steam pressure in the intermediate cylinder is excessive, in consequence of the steam velocity being too great. The following are particulars:—

Screw Steamer "Para"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	19	35	53
Length of Stroke, inches	33	33	33
Revolutions per minute	62	62	62
Indicated Horse-power, 620 total	201	213	206
Initial Stress, lbs.	27499	39582	30886
Range of Temperature, Fahr.	68·7°	75·8°	84°

Sequence of Cranks—high, low, intermediate.

In Table 3 is given a comparative statement of results from an approximately similar trio of boats in the same trade and under the same management on a round voyage to Java under average conditions. The triple engines in the "Jacatra" are of the same general design as those in the "Para," but of

greater power; the compounds in the two other boats are of the ordinary type.

TABLE 3.—*Comparative Results from three Steamers with Compound and with Triple-Expansion Engines.*

Name of Screw Steamer	Fellinger	Padang	Jacatra
Length, feet and inches	286 2	300 0	314 0
Breadth, feet and inches	35 0	37 0	37 9
Draught, feet and inches	20 3	21 9	21 6
Dead Weight carried, tons	2600	3000	3300
Type of Engines	Compound	Compound	Triple
Boiler Pressure, lbs. per sq. inch	70	76	140
Speed, knots per hour	9	9½	10
Indicated horse-power, total	660	790	890
Coal consumption per day, tons	15½	18	13½
Ditto per I.H.P. per hour, lbs.	2·19	2·13	1·41
Quality of Coal used	German	Cardiff	Mixed

In Figs. 3 and 4, Plate 90, are represented the triple engines of the Union Company's s.s. "African" and Messrs. Glover Brothers' s.s. "Shakespear." The design differs from that in the "Para" and "Jacatra" in having the valves situated over the condenser, thus doing away with the exhaust belt round the low-pressure cylinder, and giving a free open front to the engines; all the working parts are thereby rendered easily accessible, with every facility for overhauling. Combined diagrams taken from the "Shakespear" under average working conditions are shown in Figs. 23 and 24, Plate 99, which have already been referred to (page 480). The equalities of temperatures, initial stresses, and powers, are as near as it is practically possible to get them; and this result has been obtained by carefully considering the various points which influence the efficiency of the engine. The combined diagrams in Figs. 27 and 28, Plate 101, are a set taken on the trial trip of the "African" in Stokes Bay, showing 1086 horse-power developed at 85½ revolutions per minute; they thus prove that there is a sacrifice of weight in triple engines when making no more than 60 revolutions per

minute, inasmuch as the power developed at 66 revolutions per minute by the duplicate engines of the "Shakespear," Fig. 23, Plate 99, is much less, namely 871 horse-power. The following are particulars :—

Screw Steamer "African"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	21	34½	55½
Length of Stroke, inches	36	36	36
Revolutions per minute	85½	85½	85½
Indicated Horse-power, 1086·7 total	377·9	364	344·8
Initial Stress, lbs.	35322	36635	33868
Range of Temperature, Fahr.	71·7°	69°	73·7°

Sequence of Cranks—high, low, intermediate.

Crank-shaft Stresses: maximum 121, mean 100, minimum 75·2.

The combined diagrams in Fig. 29, Plate 102, are from the original compound engines of the Union Company's s.s. "Anglian," taken under average conditions on a voyage to the Cape. The mean consumption of coal per day over eight voyages was 24 tons, or about 2·1 lbs. per indicated horse-power per hour. The compound engines were of the ordinary two-cylinder type, the valves being directly over the screw-shaft, and driven by the usual link-motion. The diagrams in Fig. 30, Plate 102, were taken on a trial trip after the engines had been converted to triple-expansion; and the following are particulars :—

Screw Steamer	Compound.		Triple-Expansion.		
"Anglian"	High.	Low.	High.	Inter.	Low.
Diameter of Cylinders, inches	43	76	26	42	69
Length of Stroke, inches	42	42	42	42	42
Revolutions per minute	58	58	69	69	69
Indicated Horse-power	537	528	538	523	514
	1065 total		1575 total		
Initial Stress, lbs.	66075	69181	52824	57494	50480
Range of Temperature, Fahr.	70·5°	75·1°	71·4°	71·4°	79°

Sequence of Cranks— . . . . . high, low, intermediate.

On her voyage to the Cape, the average speed being exactly the same as in the eight voyages above referred to, the coal consumption

was one-third less, namely 16 tons per day; and as she is placed on a foreign station where the cost of fuel is about £2 per ton, the economy of the conversion is obvious. The method of converting consisted in replacing the old high-pressure cylinder by a new intermediate cylinder, and adding a new high-pressure engine complete on the forward end of the screw-shaft, the high-pressure and intermediate valves being driven by sliding-block gear similar to that shown in Plates 89 and 91. By arranging the valve casings at the side of the high-pressure and intermediate cylinders, the distance fore and aft over the present engines is very little more than before, although the power is now sufficient to drive the vessel one knot an hour faster than her former maximum speed.

Diagrams from the Orient Company's s.s. "Lusitania" are shown in Figs. 31 and 32, Plate 103. The original compound engines were of the two-cylinder type, with an expansion valve on the high-pressure cylinder. The diameters of the cylinders were 58 and 103 inches, with a stroke of 4 feet; and the boiler pressure was 55 lbs. per sq. inch. The diagrams in Fig. 31 were taken under ordinary working conditions on a voyage from London to Sydney, the average daily consumption being 52 tons of Welsh coal. The old cylinders were afterwards replaced by new ones, and a high-pressure engine was added complete, its valve being worked by swinging-link gear like that shown in Plates 90 and 92. By arranging the intermediate and low-pressure slide-valves between the intermediate and low-pressure cylinders, the old gear was utilised; and by reducing the valve casings to modern proportions, the distance lengthways over all the three new cylinders is one foot less than before. The diagrams in Fig. 32 represent the present average working conditions of the engines, the increased power propelling the vessel at a much higher speed. The coal consumption at this increased power is about 50 tons per day; but travelling at the former speed the consumption is reduced from 52 tons to 37 tons; so that, allowing eighty steaming days for a return voyage to Australia, the saving of coal is 1,200 tons, whilst the cargo-carrying capacity is largely increased. The following are particulars:—

Screw Steamer	Compound.		Triple-Expansion.		
"Lusitania"	High.	Low.	High.	Inter.	Low.
Diameter of Cylinders, inches	58	103	36	60	96
Length of Stroke, inches	48	48	48	48	48
Revolutions per minute	56	56	65	65	65
Indicated Horse-power	1230	1100	1100	1110	1105
	2330 total			3315 total	
Initial Stress, lbs.	114931	116652	99754	111685	97715
Range of Temperature, Fahr.	71·9°	78°	71°	68·5°	76°
Sequence of Cranks—			high, low, intermediate.		

The foregoing results represent a fair average of those obtained from thirty triple-expansion engines, all of the three-crank type, which have been designed by the writer during the last three years; and are sufficient to prove that this kind of engine is most efficient, and is undoubtedly the engine of the future.

Artificial Draught for Boilers. — The next step in marine engineering is probably the application of artificial draught to boiler furnaces. The combined diagrams in Figs. 33 and 34, Plate 104, were taken from the engines of the s.s. "Stella," belonging to Messrs. Herskind and Woods, between Hartlepool and Dover on her voyage to Bombay; and as a steady boiler-pressure is always maintained, the engine-power may be considered as constant. The following are particulars :—

Screw Steamer "Stella"	High.	Intermediate.	Low.
Diameter of Cylinders, inches	22	37½	60
Length of Stroke, inches	39	39	39
Revolutions per minute	61½	61½	61½
Indicated Horse-power, 932·5 total	291	331·5	310
Initial Stress, lbs.	32498	39275	37463
Range of Temperature, Fahr.	70°	70·7°	78°

Sequence of Cranks—high, low, intermediate.

Crank-shaft Stresses : maximum 117, mean 100, minimum 69·5.

The average speed between port and port from Hartlepool to Bombay was fully 9 knots per hour, the dead weight carried was 3,800 tons, and the daily consumption of north-country coal was 13·6 tons.

This performance is very remarkable, when the dimensions of the ship are considered, namely—length 302 feet, breadth 38 feet, and displacement coefficient as high as 77 per cent.

The arrangement of the plan for artificial draught is shown in Figs. 36 to 41, Plates 105 and 106. The special features are the method employed for heating the air both outside and inside the uptake, and the application of balanced fire-doors DD, Fig. 36, which on being opened shut off automatically the hot air supplied by the fan, both above and below the fire-bars. This is the first application of artificial draught to the boilers of triple-expansion engines; and should the results fulfil expectations, there is little doubt that the plan will be extensively adopted, as being yet another step towards economy of fuel.

Memorandum respecting Diagrams.

All the indicator diagrams shown have been drawn out from actual indicator cards. The theoretical adiabatic expansion curve has been constructed from the formula for the relation between the pressure and the volume in the adiabatic expansion of steam:—namely that the pressure raised to the ninth power varies inversely as the volume raised to the tenth. The theoretical curve is in all cases drawn tangential to the high-pressure indicator line. The virtual or effective cut-off is obtained by drawing a horizontal line across the top of the high-pressure diagram, at such a level that the area of the corner A of the diagram above the line is equal to the area of the vacant corner B below it, Fig. 7, Plate 93. Temperatures are given in degrees Fahr., and denote the total range in each cylinder. Initial stresses are given in lbs., and denote the product of the initial steam-pressure in each cylinder multiplied by the area of that cylinder.

The twisting moments on the crank-shaft have been calculated by the following formula, the weight of the moving parts being neglected:—

$$\textit{Twisting moment in inch-tons} = \frac{p \times a \times l \times \sin(\theta + \phi)}{2240 \cos \phi}$$

where p is the effective steam-pressure in lbs. per square inch, measured on the indicator diagram at the point corresponding with the angle θ of the crank; a is the area of the cylinder in square inches; l is the length of the crank in inches; and ϕ is the angle of obliquity of the connecting-rod, corresponding with the angle θ of the crank.

TABLE 1. (*see continuation to page* 496)

Three days' Log of Triple-Expansion Engines in S.S. "Para."

	1883. April.	Watch.	Length of Watch. H. M.	Vacuum Gauge. Inches of Mercury.	Steam Gauge. Lbs. per square inch.	Revolutions. Total per watch.	Revolutions. Average per minute.	
	1	2	3	4	5	6	7	
a	25 noon	12 to 4	4 0	27·25	146	14774	61·56	*a*
	p.m.	4 to 8	4 0	27·25	148	14935	62·19	*b*
c	p.m.	8 to 12	4 0	27·25	146	14682	61·17	*c*
d	26 a.m.	12 to 4	4 0	27·25	146	14593	60·8	*d*
e	a.m.	4 to 8	4 0	27·25	145	14737	61·4	*e*
f	a.m.	8 to 12	4 9	27·25	146	15391	61·81	*f*
g	Average for first day.		**24 9**	**27·25**	**146·3**	**89112**	**61·5**	*g*
h	26 noon	12 to 4	4 0	27·25	147	14862	61·9	*h*
i	p.m.	4 to 8	4 0	27·25	146	14891	62	*i*
j	p.m.	8 to 12	4 0	27·25	145	14994	62·4	*j*
k	...	...	...	...	146	...	62·4	*k*
l	27 a.m.	12 to 4	4 0	27·25	145	14645	61·0	*l*
m	a.m.	4 to 8	4 0	27·25	146	14821	61·7	*m*
n	a.m.	8 to 12	4 9	27·25	145	15248	61·2	*n*
p	Average for second day.		**24 9**	**27·25**	**145·7**	**89461**	**61·74**	*p*
q	27 noon	12 to 4	4 0	27·25	145	14632	61·0	*q*
r	p.m.	4 to 8	4 0	27·0	146	14836	61·8	*r*
s	...	...	...	...	147	...	61·8	*s*
t	p.m.	8 to 12	4 0	27·0	145	14648	61·0	*t*
u	28 a.m.	12 to 4	4 0	27·0	145	14497	60·4	*u*
v	a.m.	4 to 8	4 0	27·25	146	14759	61·5	*v*
w	a.m.	8 to 11·42	3 42	27·25	146	13634	61·4	*w*
x	...	...	...	...	146	...	61·4	*x*
y	Average for third day.		**23 42**	**27·12**	**145·7**	**87006**	**61·18**	*y*
	Average for Three days.		**72 0**	**27·20**	**145·9**	**265579**	**61·47**	*z*

(*see continuation on next page*) TABLE 1.

Three days' Log of Triple-Expansion Engines in S.S. "Para."

Mean Effective Steam Pressures. Lbs. per sq. inch. *See* Fig. 35, Pl. 105.

	High-pressure Cylinder 19 inches diameter × 33 inches stroke.			Intermediate Cylinder 35 inches diameter × 33 inches stroke.			Low-pressure Cylinder 53 inches diameter × 33 inches stroke.			
	Top.	Bottom.	Mean.	Top.	Bottom.	Mean.	Top.	Bottom.	Mean.	
	8	9	10	11	12	13	14	15	16	
a	63·8	66·7	65·2	22·1	20·4	21·25	9·0	9·5	9·25	*a*
b	68·9	67·9	68·4	22·0	20·4	21·2	9·4	10·1	9·75	*b*
c	66·0	66·0	66·0	22·0	20·0	21·0	9·0	9·5	9·25	*c*
d	66·4	68·0	67·2	24·1	23·3	23·7	7·6	8·6	8·1	*d*
e	68·0	67·4	67·7	23·3	22·2	22·75	7·6	8·6	8·1	*e*
f	63·6	66·1	64·85	22·2	20·3	21·25	9·0	9·5	9·25	*f*
g	**66·1**	**67·01**	**66·55**	**22·61**	**21·1**	**21·85**	**8·6**	**9·3**	**8·95**	*g*
h	65·4	66·0	65·7	23·8	22·7	23·25	8·8	9·3	9·05	*h*
i	66·6	67·4	67·0	23·4	21·8	22·6	7·8	8·5	8·05	*i*
j	66·2	66·6	66·4	22·3	19·8	21·05	8·6	9·1	8·85	*j*
k	67·6	67·0	67·3	21·6	19·8	20·7	9·0	9·6	9·3	*k*
l	68·0	67·3	67·65	23·3	21·6	22·45	7·8	8·5	8·15	*l*
m	69·7	70·6	70·15	22·5	20·7	21·6	9·4	9·6	9·5	*m*
n	67·2	69·4	68·8	22·9	20·9	21·9	9·1	9·7	9·4	*n*
p	**67·24**	**67·75**	**67·49**	**22·82**	**21·04**	**21·93**	**8·64**	**9·18**	**8·91**	*p*
q	69·7	70·3	70·0	22·7	20·0	21·35	8·3	8·6	8·45	*q*
r	67·0	69·2	68·1	22·9	21·7	22·3	7·8	8·3	8·05	*r*
s	69·0	69·7	69·35	21·8	21·2	21·5	9·2	9·7	9·45	*s*
t	67·3	68·6	67·95	23·6	22·4	23·0	7·9	8·5	8·2	*t*
u	66·0	67·4	66·7	22·2	20·2	21·2	8·7	9·0	8·85	*u*
v	66·4	66·4	66·4	21·6	20·0	20·8	9·3	9·7	9·5	*v*
w	68·2	69·4	68·8	22·3	20·5	21·4	9·5	9·0	9·25	*w*
x	68·4	69·0	68·7	22·5	20·6	21·55	8·8	9·2	9·0	*x*
y	**67·72**	**68·72**	**68·22**	**22·45**	**20·82**	**21·63**	**8·68**	**9·0**	**8·84**	*y*
z	**67·02**	**67·82**	**67·42**	**22·62**	**20·98**	**21·80**	**8·64**	**9·16**	**8·90**	*z*

TABLE 1. (*continued from preceding page*)

Three days' Log of Triple-Expansion Engines in S.S. "Para."

	Mean Back-Pressures. Lbs. per square inch.			Revolutions per minute.	Indicated Horse-Power.				
	High.	Inter.	Low. *Vacuum.*		High.	Intermediate.	Low.	Total.	
	17	18	19	20	21	22	23	24	
a	47·5	3·0	12·5	62	191	211	210·8	613	*a*
b	48·0	3·5	12·5	62·5	202	212	217	631	*b*
c	48·0	2·75	12·5	62	194	209	211	614	*c*
d	50·0	2·75	12·5	61	194	231	182	607	*d*
e	52·0	2·25	12·25	62	199	226	185	610	*e*
f	47·0	3·0	12·5	62	190	211	211	612	*f*
g	**48·75**	**2·87**	**12·5**	**61·9**	**195**	**216·6**	**202·8**	**614·4**	*g*
h	50	2·75	12·5	62	193	231	207	631	*h*
i	52	2·0	12·5	61·5	195	223	182	600	*i*
j	47	2·5	12·0	62·2	196	210	203	609	*j*
k	48	2·75	12·5	62·5	199	208	214	621	*k*
l	50	2·25	12·25	62	198	223	186	607	*l*
m	50	3·0	12·25	62·5	207	217	218	642	*m*
n	49	3·0	12·25	62	201	218	214	633	*n*
p	**49·42**	**2·6**	**12·32**	**62·1**	**198·4**	**218·5**	**203·4**	**620·3**	*p*
q	52	2·5	12·25	61·5	203	211	191	605	*q*
r	52	2·0	12·0	61·5	198	220	182	600	*r*
s	48	3·0	12·25	62	204	214	216	634	*s*
t	51	2·25	12·0	61	196	225	184	605	*t*
u	50	2·5	12·25	61·5	194	210	200	604	*u*
v	49	2·75	12·5	61·5	193	206	215	614	*v*
w	51	3·0	12·5	62	202	213	211	626	*w*
x	50	2·75	12·5	62	201	214	206	621	*x*
y	**50·37**	**2·59**	**12·28**	**61·6**	**199**	**214·1**	**200·6**	**613·7**	*y*
z	**49·51**	**2·68**	**12·36**	**61·86**	**197·4**	**216·4**	**202·2**	**616**	*z*

(*see continuation on next page*) TABLE 1.

Three days' Log of Triple-Expansion Engines in S.S. "Para."

	Mean Effective Steam Pressures reduced to area of low-pressure cylinder. Lbs. per square inch.				Distance run.		Coal burnt.		
					Total.	Per hour.	Total per day.	Per I.H.P. per hr.	
	High.	Inter.	Low.	Total.	Knots.	Knots.	Tons.	Lb.	
	25	26	27	28	29	30	31	32	
a	8·38	9·27	9·25	26·9	1 knot = 1·1528 mile.	...	...	...	*a*
b	8·79	9·25	9·75	27·79		...	...	...	*b*
c	8·48	9·17	9·25	26·90		...	...	...	*c*
d	8·63	10·34	8·10	27·07		...	...	...	*d*
e	8·70	9·93	8·10	26·73		...	...	...	*e*
f	8·33	9·27	9·25	26·85		...	...	...	*f*
g	**8·55**	**9·53**	**8·95**	**27·04**	**220**	**9·1**	**10·38**	**1·56**	*g*
h	8·44	10·14	9·05	27·63	...	...	...	...	*h*
i	8·61	9·86	8·05	26·52	...	...	...	...	*i*
j	8·53	9·19	8·85	26·57	...	...	...	...	*j*
k	8·65	9·03	9·3	26·98	...	...	...	...	*k*
l	8·69	9·80	8·15	26·54	...	...	...	...	*l*
m	9·01	9·45	9·5	27·94	...	...	...	...	*m*
n	8·84	9·57	9·4	27·81	...	...	...	...	*n*
p	**8·68**	**9·57**	**8·91**	**27·16**	**224**	**9·27**	**10·58**	**1·58**	*p*
q	8·99	9·32	8·45	26·76	...	...	...	...	*q*
r	8·75	9·73	8·05	26·53	...	...	...	...	*r*
s	8·91	9·38	9·45	27·74	...	...	...	...	*s*
t	8·72	10·04	8·2	26·96	...	...	...	...	*t*
u	8·57	9·25	8·85	26·67	...	...	...	...	*u*
v	8·53	9·08	9·5	27·11	...	...	...	...	*v*
w	8·84	9·34	9·25	27·43	...	...	...	...	*w*
x	8·83	9·41	9·00	27·24	...	...	...	...	*x*
y	**8·76**	**9·44**	**8·84**	**27·04**	**216**	**9·11**	**9·79**	**1·50**	*y*
z	**8·66**	**9·51**	**8·90**	**27·07**	**220**	**9·16**	**10·25**	**1·54**	*z*

TABLE 1. (*concluded from page* 492)

Three days' Log of Triple-Expansion Engines in S.S. "Para."

	Sea. Wind. Sails set.	Coal and Firing. Dimensions of Steamer.
	33	34
a	Moderate sea. Ship rolling. Square sails set.	All the coal used was measured in half-tons, three measures being weighed during each twenty-four hours, and the mean weight taken at the end of the trial.
b		
c	Light airs to light breeze on port quarter.	
d		
e	Moderate breeze on starboard beam. Square sails and main staysail.	
f		
g	Moderate swell. Ship rolling.	The quality was soft north-country coal, yielding 10 per cent. of ash.
h		
i	Light breeze on starboard beam.	
j		A heavy beam swell running throughout the trial caused the ship to steer badly.
k	Square sails, fore trysail, and main staysail.	
l		
m	Moderate sea.	
n		Each fire was cleaned once in twenty-four hours; and no appreciable difference in steam pressure was observed during cleaning.
p	Light breeze on starboard bow.	
q		
r	Moderate breeze on starboard bow, and before starboard beam.	
s		
t	Moderate breeze before starboard beam.	
u		Ft. Ins. Length of Ship . . 257 6
v	Light breeze on starboard beam.	Extreme breadth . . 34 6
w		Draught on leaving Hartlepool . . . 19 4
x	Square sails and staysails set.	
y		Tons. Dead weight carried . 2398

Discussion.

The President mentioned that the author of the paper just read, the late Mr. Robert Wyllie, was represented on the present occasion by his successor, Mr. D. B. Morison, by whom he had been ably assisted in the preparation of the paper and of the extensive series of diagrams by which it was so elaborately illustrated.

Mr. Morison was sure that, had the late Mr. Wyllie been spared, he would have been only too glad to give any further results of his experience with triple-expansion engines in addition to those already embodied in his paper; for it had been a noticeable feature in his brilliant career that he was ever willing to lend his valuable aid to assist the progress of the profession in which he had obtained so high a reputation. As he was also strongly opposed to attaching his name to any statements of which the accuracy might be open to question, the Members might rest assured that the various results enumerated in the paper were by no means exaggerated, but were a true record of facts obtained with every possible care. In marine engineering, as much as in any other department of engineering, the element of carefulness or a complete analysis of practical results was very essential, for preventing the adoption of incorrect principles. The paper itself contained a remarkably large mass of information in an extremely condensed form; for it had been the author's wish to touch upon as many as possible of the numerous points that had a direct bearing on the efficiency of the triple-expansion engine. Owing therefore to the very wide scope of the paper, there might be found in it some matters requiring amplification, which he should be very glad to explain as far as he was able, inasmuch as, having been closely connected with Mr. Wyllie for many years, he had had every opportunity of becoming acquainted with his general engineering views.

In dealing with indicator diagrams, the greatest care was necessary to prevent the many inaccuracies possible. With this view therefore the originals of the greater number of the combined diagrams now

(Mr. Morison.)

exhibited had been taken by three operators at what was practically the same instant, thus minimising the inaccuracies due to the fluctuations of steam pressure in the boiler and in the two receivers; nevertheless these inaccuracies were generally discernible in various degrees when the diagrams from the three cylinders came to be drawn out together in the combined form here shown. The greatest care was required in taking the indicator diagram from the high-pressure cylinder; for from experience he had found it somewhat difficult to obtain a true diagram, on account of the tendency of the indicator piston to stick at the top of its stroke. The sticking was due to the very high pressure forcing various impurities between the piston and cylinder of the indicator; it naturally gave the diagram an excellent appearance, and an almost straight initial steam-line, which was nearly always inaccurate; in fact, in dealing with indicator diagrams the greatest care was necessary, or the results were utterly valueless. He had brought for inspection the original diagrams actually taken on the trial of the "Para," from which would be seen their true relative forms; and the combined diagrams exhibited in illustration of the paper were the mean of those taken from the top and bottom of each of the three cylinders, the engine being fitted with the sliding-block valve-gear. For illustrating the effect of the swinging-link valve-gear, of which he exhibited a working model, he had also brought the original diagrams taken from the China tea steamer "Kaisow," which made an economical voyage last year.

The results obtained from the "Stella" he believed had been received by some engineers with a certain amount of reserve; and therefore in proof of their correctness he had now the pleasure of submitting the engineer's abstract log, showing the total coal consumed on the first voyage, and also the daily speed of the ship. She was now making her second voyage, and according to latest advices was travelling at an average speed of $8\frac{1}{2}$ knots an hour on a daily consumption of 14 tons of very inferior coal. He quite agreed with what Mr. Fothergill had said in his recent paper read before the British Association, that the economy resulting from the application of artificial draught was to be realised by obtaining higher evaporative

efficiency with good coal, and not by attempting to consume rubbish containing about 40 per cent. of clinker and ash, such as was often found in unwashed duff coal.

For the safe employment of high pressures, the all-important requisite which Leeds might well be proud of contributing, namely Fox's corrugated flues, had been fitted in the whole of the high-pressure boilers for the thirty triple-expansion engines designed by Mr. Wyllie; and in no single instance had these furnaces given the slightest trouble.

Mr. William Parker was confident he should only be expressing the general feeling of the Members when he said that they all deplored the loss sustained by the marine engineering profession through the lamented death of the author. Personal acquaintance had led many marine engineers to look forward to the valuable results likely to accrue to the engineering world from Mr. Wyllie's great abilities, which had been so effectively displayed in the paper just read. This paper was indeed one of the greatest importance, not only to engineers generally, but also to steamship owners, especially at a time like the present, when so little profit was being realised from steamships. It was now acknowledged he believed by nearly all steamship owners that the triple-expansion engine was the engine of the future, and that the compound engine was obsolete. In a paper which he had had the honour of reading in July last at the Institution of Naval Architects in Liverpool, on the progress of marine engineering, he had tried to shadow forth what would be the future of the mercantile steamship so far as economy in fuel was concerned. In doing so he had pointed out that the steamships of the present day were working under conditions requiring 35 per cent. less coal than was required five years ago; and that what seemed most likely to bring about a further advance in the immediate future was the introduction of forced combustion, which he was glad to see so favourably spoken of in the present paper. In his own paper he had given the results of some steamships built under his own inspection, and those results went far to endorse all that had been said by Mr. Wyllie and Mr. Morison. Of two large

(Mr. William Parker.)

steamers built for the Peninsular and Oriental Steamship Co., each 6000 tons burden, and having exactly the same dimensions, exactly the same lines, and exactly the same power, one was propelled by a triple-expansion engine at a working pressure of 145 lbs. per square inch, and the other by an ordinary compound engine working at 90 lbs. per square inch. They both steamed to Australia at the same speed of twelve knots an hour, and the vessel with the triple-expansion engine burned 1200 tons less coal than that with the compound engine. In the case of two other comparatively modern vessels, the first was fitted with compound engines working at a pressure of 90 lbs. per square inch, and carried a cargo of 3000 tons including the bunker coal. She steamed ten knots an hour, and burned 20 tons of coal per day. The second vessel was fitted with a triple-expansion engine working at a pressure of 150 lbs. per square inch, and made her voyage to India in the same length of time as the first, and burned the same amount of coal, but carried 4200 tons of cargo, or 1200 tons more than the first vessel. Another case, to which he was glad that reference had been made by Mr. Wyllie, was that of a vessel which had been altered from the compound to the triple-expansion principle. The vessel had been fitted in 1871 by Messrs. Laird with ordinary compound engines working at 60 lbs. per square inch, which had been altered to triple engines with new boilers working at 150 lbs. per square inch; and while the original speed had been maintained, the consumption of coal had been diminished by 25 per cent. There had been other cases of a similar kind, justifying the statement that steamship owners were now quite satisfied that the triple-expansion engine was the engine of the future, and that the compound engine, which had hitherto given such good results, was now becoming obsolete. Already there were 150 sets of triple-expansion engines running, which were giving results such as those he had mentioned; and he would endeavour to give the result of his experience as to the different kinds of practice that existed in the country, with regard to some of the points to which reference had been made in the paper.

First, as to the position of the cylinders, it was a disputed point whether the three cylinders should be placed fore and aft in the

vessel, or whether they should be arranged on the tandem principle. In the "Arawa," built by Messrs. Denny, there were four cylinders working upon two cranks, the high-pressure cylinder exhausting into an intermediate cylinder, and the intermediate cylinder into two low-pressure cylinders. In the "Australasian" there were three cylinders arranged fore and aft, and working on three cranks. The result of their performances, as shown by the coal consumption and the number of tons carried, was he thought in favour of the vessel with four cylinders as superior to that with three cylinders.

As to steam-jackets, he agreed with the author of the paper that the intermediate and low-pressure cylinders should certainly be steam-jacketed. Unfortunately marine engines had not the same advantage as those on shore, where there was every facility for looking after the steam-jackets. At sea the jackets were seldom properly attended to, especially in heavy weather.

With reference to the ratios of the cylinder capacities, there was a great difference of opinion as to what the proper ratios should be. Taking the ratios of the cylinders in the 150 engines built since the introduction of triple expansion, he had found that the ratio of the high-pressure cylinder to the low-pressure varied as much as between 1 to 4·8 and 1 to 7·5, with a difference in boiler pressure of only 10 lbs. That was a very great variation, and it was difficult to see why there should be such a range, unless it were simply because the five years during which the engines had been running included the early stages of their development. According to his experience the best ratios for the capacities would be found to be 1 and 2·5 and 7·5 for the high and intermediate and low-pressure cylinders respectively, with a cut-off in each at about 60 per cent.

Another important point was the question of three cranks or two. In looking at the torsional diagrams exhibited, he found that the twisting moments there given went to show that a three-cylinder engine with three cranks set at equal angles must necessarily work more uniformly than an engine with two cranks set at right angles. Having taken the trouble however to calculate the twisting moments in a number of engines, both with two and with three cranks, he had found that there was not anything like so great a difference as was

(Mr. William Parker.)

generally imagined. There was certainly a slight difference in favour of three cranks; but the two-crank engine he believed could be made to work almost as uniformly. As to the formula employed for calculating the twisting moments, it was stated in the memorandum appended to the paper that the weight of the moving parts had here been neglected. But in his own calculations of the twisting moments he had found that the weight and momentum of the moving parts—the piston, the piston-rod, and the connecting-rod —were considerable, and that torsional diagrams drawn without taking into consideration the weight and momentum were very misleading indeed. In fact in one of the engines referred to in the paper he had found that the error so arising represented something like 8 lbs. of steam pressure; and when it was remembered that in the low-pressure cylinder alone this amounted to as much as 70 per cent. of the total pressure, it was evident that it would have been better in drawing out the three-crank diagrams to take into consideration the weight and momentum of the moving parts.

As showing how the triple-expansion engine was progressing, and how steamship owners were taking advantage of it, he might mention that only a few days previously he had happened to meet the representative of one of the largest mail companies, who informed him that their engines which had been altered to triple expansion at the works of Messrs. Richardson at Hartlepool, under the management of the late Mr. Wyllie, had given so much satisfaction that, although they had now only four vessels so completed, they had determined to alter the whole of their fleet, and had already given an order for another six to be similarly altered at once. They found that the difference between the consumption of the engines in their old form and as now altered just made a dividend.

Among the Members present he was very glad to see two who had been largely instrumental in bringing about the economical results which he had mentioned: namely Mr. Riley, of the Steel Company of Scotland, who had had so much to do with the introduction of mild steel; and Mr. Samson Fox of Leeds, to whose energy and perseverance the country was so much indebted for the

introduction of corrugated boiler-flues. Without the high steam-pressures which by these means had now been rendered practicable, the success already realised by the triple-expansion engine could never have been attained.

Mr. Charles Cochrane enquired what was the exact meaning intended in the recommendation in page 475 of the paper, that the theoretical absolute terminal pressure in the low-pressure cylinder should not exceed 10 lbs. per square inch. According to what seemed to be the literal signification of the expression used, did this mean a vacuum of only 5 lbs. below the atmosphere? If so, what was the back-pressure when the exhaust took place?

Mr. Morison replied that the meaning was that the final pressure at the end of the stroke in the low-pressure cylinder, just before the exhaust-port opened to the condenser, should be about 10 lbs. above a perfect vacuum; or in other words the low-pressure cylinder should expand the steam down to a vacuum of about 5 lbs. below atmosphere, as illustrated in Fig. 15, Plate 96. The back-pressure when the exhaust took place was seen from the same diagram to be about $2\frac{1}{2}$ lbs. above a perfect vacuum, being equivalent to a vacuum of rather more than 12 lbs. below atmosphere.

Mr. Cochrane observed it must be apparent that, whatever the quality of the coal used, it was capable of evaporating different quantities of water according to the boiler in which the combustion was effected; and in connection with the present extremely valuable paper he could not help feeling that the consideration of the economy effected ought to be divided into two separate parts, one having relation to the boiler duty and the other to the engine duty. For with the great variation that was met with in the evaporative duty of coal, it would be seen how impossible it was to separate the actual work done by the engine from that done by the boiler. In discussing a matter of this kind therefore, he considered that some more scientific standard of reference ought to be adopted than the weight of coal consumed per

(Mr. Charles Cochrane.)

H.P. per hour; inasmuch as the engine duty and the boiler duty were here so completely mixed up together that no separation was possible unless it were made in the paper itself. The only suitable standard he considered was the total weight of steam used per I.H.P. per hour. In that way alone could the faults of the engine be detected, and a correct knowledge be obtained of exactly what it was doing, irrespective of all those conditions which affected the evaporative duty of the boiler, such as the temperature of the feed-water, and the use of an artificial draught and of heated air.

As a valuable addition which might be made to the information already given in the paper, it occurred to him to suggest that, where the velocity of the steam had really shown itself in the wire-drawn condition of the indicator diagram, there were the elements for ascertaining what ought to be the limit of velocity for the steam, in order to get the full expansion out of it without any wire-drawing. As the size was known of the ports which had failed to give perfect satisfaction, there was here an excellent opportunity for ascertaining under the varying conditions of pressure what was the limit of velocity for the steam. Such information would be most useful for deciding upon the size of the steam ports in constructing any engine. His own impression was that the lineal velocity should not exceed 40 feet per second in order to obtain the best results. What lower velocities were necessary at the intermediate cylinder and the low-pressure cylinder were matters of actual experiment, which he thought were capable of being ascertained by means of indicator diagrams examined in connection with the known sizes of the ports.

Professor Alexander B. W. Kennedy protested against the three-cylinder engine not being called a compound; surely it was a three-cylinder compound, just as much as its predecessor was a two-cylinder compound. He should like to support Mr. Cochrane's request, that if possible Mr. Morison should give the size of the ports in these engines, because a great point had been made of that matter in the paper; and if this information could possibly be added to that already given, it would render engineers still more indebted for the very large amount of information which Mr. Wyllie had put before them in so very concise a form.

This question of triple-expansion engines had been a good deal discussed lately. Besides the paper recently read at Liverpool by Mr. Parker, the subject of marine-engine economy had also on the same occasion been touched upon in Mr. John's paper. The present contribution from Mr. Wyllie was also a most important one. With the many feelings of satisfaction however, with which he had read all those papers, there was one feeling of dissatisfaction that he had experienced throughout, arising really from exactly the cause that Mr. Cochrane had touched upon: namely, that although the marine-engine industry was one which was perhaps the most national of all the industries of this country, and one on which this nation prided itself as being in advance of all other countries, there were not as yet any exact experiments whatever in regard to marine-engine economy. Rough statements of averages had been given, no doubt with perfect honesty, but they were statements which he would show could not be trusted entirely; and he hoped in the immediate future it might be possible to get some much more accurate data to go upon. The gentlemen whom he had mentioned were engineers who were particularly competent to go thoroughly into this matter; yet he noticed that they had to take for their data figures derived from experiments which could only be called roughly approximate. That was explicitly recognised in Mr. Wyllie's paper, where it was said (page 484) that, in order to get a correct estimate of an engine's performance, the quantity and temperature of the feed and circulating water ought of course to be considered. In the present instance, if it had been possible to measure the feed water, he was satisfied that some of the figures given in the paper would never have appeared in it at all. Having taken the trouble to work out as accurately as he could, from small-scale copies of the indicator diagrams exhibited, the steam consumption per I.H.P. per hour in the "Para," the "Anglian," the "Lusitania," the "Shakespear," the "African," and the "Stella," he had grouped the results in the accompanying Table (page 506). It was within the knowledge of all engineers, he believed, that steam quantities calculated from indicator diagrams were always too small. In ordinary compound engines with 80 lbs. boiler steam and with steam-jacketed cylinders

Consumption of Steam in Two-cylinder and Three-cylinder Compound Marine Engines.

Name of Steamer.	Number of Cylinders.	Indicator Diagrams. Plates 99–105.	Indicated Horse-Power.	Steam Consumption per I.H.P. per hour, deduced from indicator diagrams.			Nominal Coal Consumption per I.H.P. per hour.	Equivalent Evaporation from and at 212° Fahr. per pound of Coal.
				Actual Weight of Steam consumed.	Equivalent Evaporation from and at 212° Fahr.	Ditto with 15 per cent. added for initial condensation.		
Steamer. Page.	No.	Figs.	I.H.P.	Lbs.	Lbs.	Lbs.	Lbs.	Lbs.
Para . . 494–5	Three	35	616	13·4	16·1	18·5	1·54	12·0
Anglian . 487	Two	29	1065	17·9	21·1	24·3	2·10	11·6
	Three	30	1575	13·7	16·5	19·0	† 1·40 †	13·6
Lusitania . 488–9	Two	31	2330	18·0	21·2	24·4	* 2·08 *	11·7
	Three	32	3315	14·9	17·8	20·5	* 1·41 *	14·5
Shakespear 480	Three	23	871	14·3	17·1	19·7	—	—
African . 487	Three	27	1086	14·9	17·8	20·5	—	—
Stella. . 489	Three	33	932	13·7	16·4	18·9	§ 1·36 §	13·9

† About 1·40. * Welsh coal. § North Country coal.

(Professor Kennedy.)

he thought it was not too much to say that the indicator diagrams commonly did not show *more* than about 75 per cent. of the steam used. Those who had practically gone into these matters would, he believed, bear him out in saying this. Although in these triple-expansion engines a high compression was very well carried out in the first cylinder, and the high-pressure clearance was very small, and everything had been done to render the condensation of the entering steam as small as possible, yet the fall of temperature in the steam on entering the first cylinder was about as great as in the two-cylinder compound engine, as would be seen from the indicator diagram in Fig. 35, Plate 105; and there was no steam-jacket on the high-pressure cylinder. The indicator diagrams he therefore believed did not show more than about 75 per cent. of the steam actually used. But at any rate, in order to be quite safe in his calculations, he had assumed that the indicator diagrams showed as much as 85 per cent. of the steam used; and on that supposition he had calculated the consumption of steam per indicated horse-power per hour, and the quantity of water evaporated from and at 212° Fahr. per pound of fuel. The result so arrived at was that in the "Para" the evaporation was 12 lbs. of water per pound of coal, in the "Anglian" 13·6 lbs., in the "Stella" 13·9 lbs., and in the "Lusitania" 14·5 lbs. This he did not hesitate to say was impossible. With ordinary coal such as was burnt in marine boilers, from 12 to 14 lbs. of water evaporated per pound of coal, from and at 212° Fahr., was about as much as could be got even in a calorimeter; while in a boiler furnace there was necessarily an imperfect combustion to begin with, because little benefit was derived from the hydrogen, and the carbon was not all of it burnt into carbonic acid. Moreover much heat was unavoidably wasted in heating the escaping gases and the excess of air, and so on: so that he believed 10 lbs. of water evaporated per pound of coal was very good practice. A statement of 11 lbs. must be received with great reserve, as involving exceptionally good fuel and stoking; while 12 lbs. and upwards were simply not to be believed, for such figures were not consonant with anything that was known about the evaporating power of fuel. In view of these facts he thought it was high time that marine engineers should endeavour to carry out more

(Professor Kennedy.)

exact measurements and to furnish more correct data than those from which such results were worked out as he had here arrived at.

But while disagreeing with the author upon this point, and while perhaps emphasizing it a little strongly because he felt its importance so strongly, he did not by any means disagree with the author's main contention, that three-cylinder engines were better than two-cylinder engines in certain particular cases. The reason however of the real advantage of three-cylinder engines in those particular cases was quite clear. Comparing for instance the two-cylinder indicator diagram from the "Anglian," shown in Fig. 29, Plate 102, with the three-cylinder diagram from the same vessel after conversion, shown in Fig. 30, it was evident that the high-pressure diagram in Fig. 29 would pretty nearly cover the intermediate diagram in Fig. 30, if drawn to the same scale, and the two low-pressure diagrams would cover each other: because it would be seen that in Fig. 29 the initial pressure in the high-pressure cylinder was only 50 lbs., or very much the same as the initial pressure in the intermediate cylinder in Fig. 30. In this case therefore the advantage had been properly got, and in a perfectly legitimate way, by using a higher boiler-pressure, and taking additional work out of the steam by expanding it from a pressure of about 150 lbs. down to 50 lbs., which had here been done by putting in a third cylinder as the high-pressure cylinder. But there was no reason theoretically why this additional work should not be equally well obtained from the steam by two cylinders. It did not prove that three cylinders were better than two: what it did prove was that it was far better to use 150 lbs. pressure than only 50 lbs. There were important practical reasons however, connected with range of temperature and with initial condensation, which made it difficult to utilise so high a pressure as 150 lbs. in only two cylinders. But it was very necessary to be clearly understood that it was not the three cylinders which in this case made the improvement, but that it was obviously the use of a very much higher pressure of steam. These considerations did not in any way detract from the very high economy which the author had got from his engines; their excellent design was clearly shown

by the indicator diagrams exhibited, which proved how thoroughly well all the proportions had been worked out.

There was just one practical point on which he found he differed from the author and from many other practical engineers who were perhaps better able to judge of it than himself: namely that the low-pressure cylinder, as stated in page 477 of the paper, was of course the source of the greatest inefficiency. Speaking subject to correction, it was his own impression that inefficiency in the low-pressure cylinder was caused mainly by defects of the receiver supplying it and by defects of passages, and that it could therefore be remedied mainly by alterations outside the low-pressure cylinder itself; whereas it was the high-pressure cylinder which in his opinion was at present the unruly member in the engine. For it was in the high-pressure cylinder that there occurred the initial condensation which was the most serious of all the remediable causes of loss in any engine; and for any large economy he believed it was necessary at present to look to improvement in the high-pressure cylinder rather than in the low-pressure. If only some plan could be devised for using slag-glass liners to the cylinders, or in some other way making them non-conducting, it would get rid of the present abomination of sending in 20 per cent. of the steam as water, or converting it into water as soon as ever it entered the cylinder.

The indicator diagrams exhibited in illustration of the present paper might well be taken as models for expanding the diagrams obtained from two-cylinder or three-cylinder engines. Unfortunately compound-engine diagrams were often expanded without taking any account of clearance, or with the same clearance taken for all the cylinders alike; or some other blunder in that respect was committed, which rendered them absolutely useless. The plan adopted by the author, which was the same that had been used by himself eighteen years ago and of course by many other engineers also, was certainly the only correct one: namely to set off all the diagrams on the same horizontal scale of volumes, adding the clearances to the cylinder capacities proper. When this was attended to, the successive diagrams would fall exactly into their right places relatively to one another, and would compare properly with any theoretical expansion curve.

Mr. Thomas Mudd considered they were greatly indebted to Mr. Wyllie for thus making known the results of his experience with triple engines, especially at the present time when everyone who was engaged in the design and manufacture of triple-expansion engines was working out his own ideas, and feeling his way through the various practical difficulties attending higher pressures and higher temperatures, and when the very principle of triple expansion was only just emerging from the experimental stage. The paper now read was indeed a valuable legacy left by the author to the Institution and to the engineering profession at large.

Referring to the statement made in page 474 of the three most important conditions to be considered in order to obtain an efficient engine, no doubt these three conditions of equality were in themselves desirable to be fulfilled; but their effect on the efficiency he thought was hardly such as to entitle them to be called the most important conditions of efficiency. In any of the combined indicator diagrams now exhibited from triple engines in which these three conditions were best fulfilled, it was easy to see that the diagram from each individual cylinder might be so diminished in height from top to bottom that, though the same conditions should still be equally well fulfilled, the engine would no longer be working with the same efficiency. It seemed clear therefore that those could not be the sole conditions that determined the efficiency of the engine. If such a test of efficiency held good for triple-expansion engines, it might also be expected to apply equally to two-cylinder compound engines; but in the latter it had frequently been found that the efficiency was enhanced by keeping up the receiver pressure and taking more power out of the second cylinder than out of the first.

The efficiency of a triple-expansion engine, like that of every other engine, was dependent on a large number of conditions, which might all be classified under two heads, namely those affecting the efficiency of the steam, and those affecting the efficiency of the mechanism; and under these two heads the conditions relating to a triple-expansion engine were only different from those relating to a compound engine in so far as they were more numerous, owing to the increase in the number of parts. As no special reference

had been made in the paper to the efficiency of the mechanism, it seemed clear that the author's intention had only been to deal with the efficiency of the steam, and not with the efficiency of the engine as a whole. Considering this half of the question alone, it would be found that in two-cylinder and three-cylinder compound engines alike the efficiency of the steam would be higher according as there was less loss of temperature and pressure without doing work. It seemed therefore plain that the true test of efficiency of the steam remained the same for triple-expansion engines as for all others, namely the comparison of the areas or mean effective pressures of the actual indicator diagrams with those of the theoretical diagrams; and if the actual diagrams filled up the theoretical diagrams exceptionally well, it was clear that there was then a near approach to the maximum efficiency of the steam, irrespective altogether of any question of equality of temperatures and horse-powers in the successive cylinders.

It was generally recognised that the principal sources of loss in efficiency of steam in a well designed engine were the five following. First, excess of condensation over re-evaporation: this loss it was attempted to minimise by reducing the range of temperature in any one cylinder, and also by steam-jacketing. Second, drop of pressure in the receivers, making it desirable that these should not be too large, and necessitating care in proportioning the cylinders and their cut-off. Third, waste in the exhaust: which could be minimised by the production of a satisfactory vacuum, and by making the cylinder capacity large enough in proportion to the weight of steam passing through the engine for enabling the steam to expand well down towards the condenser pressure. Fourth, general radiation: which it was endeavoured to obviate by clothing the cylinders and by steam-jacketing. Fifth, clearance space, particularly in the low pressure cylinder.

In Figs. 42 to 45, Plate 107, were shown a set of indicator diagrams taken from the triple-expansion engines built under his direction for the s.s. "Abeona," a cargo steamer having a carrying capacity of 3,100 tons dead weight. She was at present in the Black Sea on her first voyage, and had carried a full cargo from Sunderland to

(Mr. Thomas Mudd.)

Constantinople at an average speed of 9½ knots per hour on an average daily consumption of 12¼ tons of north country coal; the indicated horse-power had averaged about 800, which gave a consumption of 1·43 lbs. of coal per indicated horse-power per hour. The three cylinders were 21 and 35 and 57 inches diameter with 39 inches stroke, and the diagrams exhibited had been taken at 66 revolutions per minute with 145 lbs. boiler-pressure; they showed 328 and 317 and 328 horse-power in the respective cylinders, giving a total of 973 indicated horse-power. These diagrams had been taken on a full-load trial when leaving Sunderland, and it would be seen that they filled up the theoretical diagram uncommonly well; their overlapping parts almost made up the whole of the deficiency between them, and the spaces that were still left to be accounted for were chiefly due to drop in the receivers, to clearance, and to exhaust waste, which were the three least avoidable losses. For comparing actual with theoretical indicator diagrams, he considered it preferable to use the curve which related to the actual steam passing through the engine. Both the theoretical expansion curves *a b* and *a c* in Fig. 45, Plate 107, were adiabatic curves drawn on the assumption that the ninth power of the pressure varied inversely as the tenth power of the volume. The upper curve *a b* related to the quantity of steam *a f*, which included the whole of the clearance in the high-pressure cylinder, and was only of interest so far as it showed how high the expansion curves in the several successive diagrams should rise in case the compression in the second and third cylinders were continued so far as to fill up the clearance with steam at the full initial pressure of the steam entering those cylinders. The lower curve *a c* related to the quantity of steam *a d*, which included only so much of the clearance as required to be filled with fresh steam after the compression had taken place; and it represented the expansion of the exact quantity of steam that actually passed through the engine. Consequently the area enclosed between the lines *c d a c* represented the work due to that quantity of steam in a perfect engine; and the ratio between the areas of the actual diagrams and this theoretical area represented the efficiency with which the steam was being used. The point that appeared chiefly

remarkable about these diagrams was the absence of loss between them, which he attributed largely to the sequence of the cranks being the opposite of that advocated in the paper.

This question of the sequence of the cranks was one that had a peculiar interest in three-crank engines, quite different from what it had in the two-cylinder compound. The sequence recommended in the paper was high, low, intermediate: in preference to the ordinary and only alternative sequence, high, intermediate, low. These two arrangements were commonly known as low-pressure leading and high-pressure leading respectively, which seemed to him simpler modes of expression. In a two-crank engine having cranks at right angles, the second cylinder took steam when the first piston was about at half stroke, whichever crank was leading; and if the receiver were small, it would be seen from the back-pressure line of the high-pressure diagram that the receiver pressure gradually rose with the diminishing volume of the exhausting cylinder until the low-pressure cylinder opened for admission; and then the receiver pressure declined again with the increasing volume of the low-pressure cylinder. With three cranks at equal angles, the same kind of effect was produced in a somewhat exaggerated degree. With the low-pressure crank leading—or the sequence high, low, intermediate—the piston of the exhausting cylinder had travelled back through only about one-third of its stroke when the following cylinder opened for admission; so that whilst the following cylinder was admitting steam the receiver capacity was being augmented by this cylinder more than it was being diminished by the exhausting cylinder; and for this reason an engine with the low-pressure crank leading might have smaller receivers than one with the high-pressure crank leading. With small receivers there would be a slight increase in the receiver pressure whilst the volume of the exhausting cylinder was diminishing, until the following cylinder opened for admission, and then the rapid enlargement of volume in this cylinder caused considerable reduction of the receiver pressure. The larger the capacity of the receiver, the more nearly would the back-pressure line of the exhausting cylinder approach to a straight horizontal line. With the high-pressure crank leading—

(Mr. Thomas Mudd.)

or the ordinary sequence high, intermediate, low—the piston of the exhausting cylinder had to travel back through about two-thirds of its stroke before the following cylinder opened for steam; hence if the receiver were small, the receiver pressure would rise as the volume of the exhausting cylinder diminished, until the following cylinder opened: after which there was not time for the back-pressure in the exhausting cylinder to fall much before compression began. A new condition however now came in, which had no effect when the low-pressure crank was leading; for since, with the high-pressure crank leading, the time of admission to the following cylinder was near the time of compression beginning in one end of the exhausting cylinder, it was clear that it would also be equally near the time of release from the opposite end of the exhausting cylinder; and this simultaneity of the three events of admission to the following cylinder, and compression in one end and release from the other end of the exhausting cylinder, was the point particularly to be noticed.

The consequent advantage of the high-pressure crank leading—or of the ordinary sequence high, intermediate, low—might be readily appreciated by considering the dividing lines between the successive diagrams from the three cylinders of a triple engine. When expanding in a single cylinder only, it was of course necessary for the efficiency of the steam that both the admission and the exhaust line of the diagram should be as nearly horizontal as possible; and when expanding in two cylinders with cranks at right angles, the times of release and admission were such that no greater benefit could be derived from any other than a horizontal division between the two diagrams. But when expanding in three cylinders with cranks at equal angles it did seem to be a source of increased economy that the dividing lines between the successive diagrams should be oblique instead of horizontal, the back-pressure line rising continuously during the return stroke, as in the diagrams from the high-pressure and intermediate cylinders, Figs. 42 and 43, Plate 107. In comparison with diagrams having horizontal dividing lines, it was of course clear that for equal horse-powers the oblique diagrams showed greater ranges of temperature and higher initial

pressures. But considerations respecting the times of admission with three cranks at equal angles, and respecting the detrimental effect of condensation during admission, had led him to conclude that in triple engines the oblique diagrams were preferable to those having horizontal lines of division. This conclusion was borne out generally by the working of the first four sets of triple-expansion engines designed by himself, of which two had been made with the high-pressure crank leading and two with the low-pressure crank leading; although the reports were not so full or so exact as could be desired, they went to prove that the more economical engines were those with the high-pressure crank leading, that is with the ordinary sequence of cranks—high, intermediate, low.

The explanation he thought would be found to be spread over at least three causes, two relating to the efficiency of the steam, and one to the efficiency of the mechanism. Firstly, just as the usual compression of the exhaust steam in a cylinder, at the end of the backward stroke, not only reduced the quantity of steam admitted, but also prevented loss by condensation from a sudden fall of temperature in the incoming steam, so in all probability the gradual compression throughout the whole length of the backward stroke, by raising the receiver-pressure more nearly up to the pressure of release from the opposite end of the exhausting cylinder, would prevent loss from a sudden fall of temperature in the released steam exhausting into the receiver. Secondly, with this particular sequence of cranks—high, intermediate, low—the following cylinder had opened to take steam only a little before the opposite end of the exhausting cylinder was ready to release; the released steam therefore went direct on to the following piston, the moment it was released; and thus, at the very instant when the usual condensation would have been going to occur during admission in the following cylinder, this reinforcement of released steam came in with its slightly re-evaporative effect due to its expansion, and saved the following cylinder from part of the bad effect of internal condensation. This action was well illustrated in the indicator diagrams of the "Abeona," Fig. 45, Plate 107, where in the intermediate cylinder for instance it was seen that the new

(Mr. Thomas Mudd.)

steam buoyed up the pressure to nearly the point of cut-off, overlapping the bottom of the high-pressure diagram when the two diagrams were here combined irrespectively of their relative sequence in working; the expansion curve was thereby enabled to approach well up to the theoretical curve of adiabatic expansion, and even to go slightly beyond it in the latter part of the stroke. Thirdly, the advantage which he considered to accrue to the mechanism in a triple engine making these oblique diagrams was that, when the momentum of the moving parts was taken into account, the turning forces were found to be much more equable, and the oblique diagrams were consequently far more favourable to the higher piston-speeds which triple expansion seemed likely to introduce into marine engines.

These oblique diagrams could be produced only by having the high-pressure crank leading, the sequence being high, intermediate, low; and the obliquity of the back-pressure line could easily be overdone by using receivers of too small capacity. The diagrams with horizontal lines of division however might be produced with either the low-pressure or the high-pressure crank leading; but in the latter case the receivers would require to be much larger than with the low-pressure crank leading. For the foregoing reasons he had abandoned the arrangement with the low-pressure crank leading, although before looking well into the matter he had thought that plan to be the best. All the later triple engines which he had designed had the high-pressure crank leading, as in the "Abeona."

While he admitted that one of the three conditions set forth in the paper as essentials to efficiency had an important bearing thereon—namely the range of temperature in any one cylinder—the explanations he had now offered on the question of sequence of cranks would have made it clear that he thought an advantage arose from the temperatures overlapping one another to some extent, instead of forming the minimum subdivision of the total range. Thus in the "Abeona" the total range was 217° Fahr., but the three separate ranges were made to overlap so far that their sum amounted to as much as 242°; the range was 88° in the low-pressure cylinder, and 77° in each of the other two. The fulness of the

diagrams proved that gain rather than loss was the result. Neither did there seem to have arisen any ill effect from the range of temperature in the low-pressure cylinder being ten degrees greater than in either of the other two. On this point he was also strongly of opinion that a judicious deviation from an equal subdivision of temperature among the three cylinders would give the best results; and the expansion curve in the low-pressure diagram he believed could be got still closer to the theoretical curve, if there were a still higher initial pressure in that cylinder.

On coming to consider in what way equality of initial stresses and equality of horse-powers could affect the efficiency of the steam, it seemed to him they had no direct bearing at all thereon; and only had an indirect bearing through affecting the ranges of temperature. Initial stresses were important in view of the strength of parts and the extent of bearing surfaces; and equality of horse-powers had an influence of somewhat minor importance on the efficiency of the mechanism, inasmuch as it affected the ease and regularity of turning. In the "Abeona" the initial stresses were 34,600 lbs. in the high-pressure cylinder, 43,750 lbs. in the intermediate, and 46,000 lbs. in the low-pressure; and the horse-powers, as already mentioned, were 328 and 317 and 328 respectively at 66 revolutions per minute.

In reference to steam-jackets, he agreed with the author in two important particulars. In the first place, if one cylinder only was to be jacketed, it should be the low-pressure cylinder, because he believed in having the largest range of temperature in that cylinder, and because, whatever condensation did occur therein, the greater part of the steam so condensed did not undergo re-evaporation until it was passing out into the condenser. In the next place, steam-jacketing was less advantageous in the two-cylinder than in the single-cylinder engine, and still less in the triple than in the two-cylinder engine; indeed its beneficial effect he considered had become so diminished in triple engines that in ordinary practice he had left off the jackets altogether in these engines; and that he had not gone very far astray by so doing seemed to be proved by the indicator diagrams from the engines of the "Abeona," which had no steam-jackets whatever.

(Mr. Thomas Mudd.)

With regard to cylinder ratios, a proportion that worked very well with 150 lbs. boiler-pressure and three cranks was 3–5–8 for the diameters; and this had the merit of extreme simplicity and of being easy to remember.

For obtaining even approximate equality in powers, temperatures, and stresses, it was stated in the paper (page 476) that the greatest care was required in designing the steam passages throughout the engine. But while all engineers would agree in the necessity for giving the greatest care to the designing of the steam passages, it would hardly occur to anyone that the object to be thereby attained was to get equality in horse-powers, temperatures, and stresses. The obvious aim would be to get the steam freely on to the piston and freely off again at the proper times, and so to reduce wire-drawing.

With regard to the number of cranks, he fully agreed with the author that three were vastly superior to two, wherever it was possible to apply three. The three-crank engine of the "Abeona" went into the same length of engine-room as an ordinary two-crank compound of the same power.

An ideal valve-gear was very properly described in the paper (page 483) as one that would give at both ends of the cylinder an equal distribution of steam at all grades of expansion, with a minimum of working parts, and with no undue strains. The valve-gear shown in Figs. 5 and 6, Plates 91 and 92, appeared to have no less than seven joints and an eccentric for each cylinder, or twenty-one joints for the entire engine. From what he had seen of this gear, he should certainly think it would give a satisfactory distribution of steam; but in marine work multiplicity of joints and parts was so objectionable, that no pains should be spared to avoid it. The valve-gear played so important a part in the design of an engine that it might indeed be said to determine every other feature of the engine. In engines of moderate power, say from 300 to 1200 indicated horse-power, shortness of engine fore and aft was a decided desideratum; and in view of the large number of steamers which would in the immediate future be fitted with triple-expansion engines in place of the present two-cylinder engines,

it became necessary to design a valve-gear that would accommodate the valves in some position out of the centre-line of the ship, so as to save length. In Figs. 46 and 47, Plate 108, was shown the single-eccentric valve-gear of the "Abeona," and the following were the particulars of the actual valve-setting for full gear ahead, as taken from the engine, all dimensions being given in inches:—

Single-Eccentric Valve-Gear of "Abeona." Full gear ahead.

Stroke 39 inches. Diameters of Cylinders. Inches.	Lead invariable at all grades. Inch.		Distance travelled by piston at maximum port-opening. Inches.		Cut-off. Inches.		Compression. Inches.	
	Top.	Bott.	Top.	Bottom.	Top.	Bottom.	Top.	Bottom.
High 21	0	$\frac{1}{4}$	$8\frac{1}{2}$	$7\frac{7}{8}$	$26\frac{1}{8}$	$26\frac{1}{8}$	$2\frac{5}{8}$	$3\frac{3}{4}$
Inter. 35	0	$\frac{3}{16}$	$7\frac{1}{4}$	$6\frac{7}{8}$	$23\frac{9}{16}$	$23\frac{3}{16}$	$4\frac{1}{16}$	$4\frac{1}{4}$
Low 57	$\frac{1}{8}$	$\frac{1}{4}$	$7\frac{5}{8}$	$5\frac{3}{8}$	$23\frac{5}{8}$	$22\frac{7}{8}$	$4\frac{3}{4}$	$4\frac{3}{4}$

This gear he believed gave a sufficiently perfect distribution of the steam, whilst it had only three joints, one slide, and one eccentric, or not more than one-half of the joints and parts of the gear described in the paper. It was a modification of Hackworth's gear, the motion being precisely that invented more than a quarter of a century ago by Hackworth, who in the matter of valve-gear was greatly in advance of his time, and to whom the same honour was due as to a man who by patient application had discovered a great truth.

Mr. Daniel Adamson said that, although he had had no practical experience with marine engines, he had had some collateral experience for many years with regard both to triple and to quadruple engines. When the advancement and progress of the marine engine was discussed in connection with Mr. Marshall's paper at Newcastle (Proceedings 1881, page 449), he had himself

(Mr. Daniel Adamson.)

argued (page 502) that, instead of using only one cylinder as was done by Mr. Alfred Holt of Liverpool (page 464), they should, in the modern large engines and large ships, distribute the percussive force over many crank-pins. The author of the present paper was entitled to honour for having brought this matter forwards, because his views had been established by the practical results he had given, notwithstanding that there might be theoretical doubts as to the actual boiler evaporation. Such doubts however did not affect the comparison between one steamship and another having very nearly the same boilers, and using almost identically the same coal. These results therefore appeared to him to afford a very good practical illustration as to whether the triple-cylinder engine was advantageous and practically valuable in comparison with the two-cylinder compound and with the single-cylinder engine.

The boiler-pressure, he thought, might with great advantage be raised considerably higher than the 150 lbs. mentioned in the paper and by previous speakers. The reason of the high efficiency now obtained with 150 lbs. steam was that the expansion was divided among three cylinders, so as to avoid any great reduction of temperature in any one cylinder between the initial and the terminal pressure of the steam. Already he had several boilers working at 250 lbs.; and he did not look upon this pressure as by any means a limit. As soon therefore as a higher pressure than the present 150 lbs. came to be attempted in marine engines, he expected it would be found that the quadruple engine would be the one to come to the front and to go ahead of the triple engine, if the increase of steam-pressure were as great over the triple engine as it had been in the triple engine over the two-cylinder compound. For younger engineers than himself there was therefore plenty yet to be done towards advancing the general practice and economy in the steam engine.

With regard to the introduction of triple compound engines for stationary purposes, he had himself adopted that principle in 1861–2 with the view of preventing so much variation of temperature between the initial and the final pressure in any one cylinder. Having at that time the command of only 110 lbs. boiler-pressure, he had so distributed the expansion that the maximum reduction of

temperature in the first cylinder was about 47° Fahr., while in each of the other two cylinders it was about 53°. If it were practicable by any method to determine exactly the limit that should be adopted for the reduction of temperature in any one cylinder in order to get at the greatest efficiency, it would then be known at once what was the best number of cylinders to adopt, whether three or four; and engineering practice would then advance in conformity with the conclusion so arrived at. Dividing the power over three or four crank-pins was far better than breaking the shaft by putting the whole force on a single crank. If this question of temperature was truly as important as he considered it to be, it followed that the steam-jacketing of the cylinders, or some equivalent plan, must be regarded as the very best aid that could be adopted in practice for carrying out the expansion of high-pressure steam down to low-pressure. Taking 360° Fahr. as about the temperature of the initial steam at an absolute pressure of about 160 lbs., and say about 100° as the temperature corresponding with the terminal pressure in the low-pressure cylinder and in the condenser, there would be a reduction of 260° from the initial to the terminal temperature. As it was proved by the triple engines and by others using 160 lbs. steam that it was practicable to work with high-pressure steam as hot as 360°, it must be equally practicable to work with low-pressure steam equally hot; and therefore, instead of steam-jacketing the cylinders, advantage might well be taken of Dalton's law of the expansion of gases, and additional heat might be put into the steam as it passed from cylinder to cylinder. According to the discovery made by Dalton in 1801, steam followed the same law as other permanent gases, doubling its volume under the same pressure by increasing its temperature 480°. Here therefore was a case where the steam could practically be increased 50 per cent. in bulk by raising its temperature only 240°, while there was an actual difference of 260° between the initial and the terminal pressure. Taking even a lower initial pressure of only 140 lbs. instead of 160 lbs., there would still remain a difference of 250°; so that in this case also could the steam be increased in bulk to half as much again by heating it up in its passage from cylinder to cylinder. From his own

(Mr. Daniel Adamson.)

experience in this matter he was satisfied that the practical efficiency of the steam engine could be increased by using multiple cylinders, and taking care to nurse the steam as it went along, by putting more heat into it than was due to its pressure alone. If the single-cylinder engine was rendered disadvantageous by the high initial pressure and the low terminal pressure—first of all condensing the steam and then evaporating it again, but without performing efficient work in doing so,—certainly it was desirable that there should be a much smaller reduction of temperature in any one cylinder; and this guiding element of economy was well illustrated by the triple engines described in the paper, which surpassed the double-cylinder engines, just as the double surpassed the single. Similarly he was himself thoroughly convinced from experience that the quadruple engine would greatly surpass the triple. For the high-pressure cylinder he had convinced himself that steam-jackets were not necessary, though they might be for the other cylinders working at the lower pressures. But superheating between the cylinders was what he advocated as the proper means to use for getting the greatest efficiency and economy in a compound steam-engine.

With reference to the single-eccentric valve-gear, shown in Figs. 5 and 6, Plates 91 and 92, which presented the advantage both of an efficient action and of few working parts, it should not be forgotten that the valve motion got by a diagonal slot or bar adjusted obliquely to the eccentric-rod was due to John Wesley Hackworth, who first of all introduced the plan shown in Fig. 5, where the reversing was effected by reversing the angle of obliquity at the extreme end of the eccentric-rod; and afterwards he transferred that reversing action from the end to an intermediate point in the eccentric-rod, and so got the same results that were given by the plan shown in Fig. 6. Thus in both cases, although varying somewhat in details, the principle of the single-eccentric valve-gear here shown had been given to engineers by a man whose name he was proud to recall, because he had himself been a pupil of Mr. Hackworth's father, who was the first locomotive superintendent in this country, as well as a renowned inventor and engineer.

The irregularities that might occur in diagrams taken with a good indicator did not seem to him so serious as represented by Professor Kennedy. It was true that all indicator diagrams might be somewhat irregular; but they were nevertheless the best means at present available for getting the information that was desired. In the case of the indicator diagrams now exhibited, whatever might be the results deduced from them, the statements just made by Mr. Parker, as to the efficiency and economy of the triple engines, established beyond doubt that it was most advantageous to work with three cylinders, starting with a moderately high pressure of steam. Towards the realisation of this object he had himself contributed something as long ago as 1852, by insisting that boiler flues must be in sectional lengths if it were desired to get great security; and further in 1862 he had advocated the general use of steel in the manufacture of steam boilers. The result of these early endeavours was that up to the present time he had made probably three thousand boilers nearly, all of steel and working at very high pressure, without ever having had an explosion with one of them. In this connection he considered that for the working of steam engines generally there was still a good deal of improvement in reserve, because the temperature fortunately rose slowly for any increase in pressure of steam. According to his own investigations, iron did not suffer but rather increased in strength until its temperature got up to 500° Fahr., and even then the strength was not impaired unless the metal was both alloyed with injurious elements and also contaminated with an admixture of cinder. Comparatively pure iron could certainly be heated to 550° before the temperature became dangerous; and 600° could be reached with a literally pure iron containing no alloy. Hence the temperature could be elevated considerably above the present, if only there were the means of working with proper lubricants; and with multiple cylinders there was a prospect of working at 200 lbs. pressure at least.

Inasmuch as there were not likely to be so many breakages of crank-shafts in large steamers, if the driving force were distributed over three crank-pins instead of only two, he had come to the

(Mr. Daniel Adamson.)

conclusion that the triple expansion with three cranks, as described in the paper, was the wise plan for working efficiently. At the same time he believed it was practically impossible, while maintaining exactly equal reductions of temperature in the successive cylinders, to obtain also the same horse-power in each. For meeting the inevitable inequalities of power in the successive cylinders, he should certainly recommend that the high-pressure cylinder, exerting the least power, should work upon a crank-pin on the outer end of the screw-shaft; that the middle cylinder should come next; and that the low-pressure cylinder with its vacuum, which always exerted the greatest power, should work on the last crank, furthest along the shaft. By that means the torsional strain produced by the successive cylinders would be brought upon the shaft in the most uniform way, and in the manner most conducive to its durability and strength.

A further point to be attended to was that, if the steam were worked three or four times over, it must be with a higher velocity of piston. For at 60 revolutions per minute in a triple engine the steam would have to make 180 changes per minute. Moreover if the condensation per cylinder were the same as in the single-cylinder engine, the steam ought to pass through a great deal faster. There could be no doubt, he thought, that condensation in all such cases was a question of time; and therefore the quicker the steam passed through the cylinders the more efficient it was. Furthermore a higher velocity of piston in a triple or quadruple engine would give the means of diminishing the percussive force on any one crank-pin or journal, and the engine could run faster without heating the journals.

Professor Robert H. Smith concurred in Professor Kennedy's remarks with respect to the evaporating power of boilers, and was always sceptical in regard to an evaporation of even 10 lbs. of water per lb. of coal.

The greater efficiency of the triple-expansion engines appeared from the paper to be chiefly due to the facility thereby afforded for using a much higher initial pressure; and it became a question indeed whether the employment of three or more cylinders was not

indispensable for enabling this higher initial pressure to be used without sacrificing other practical advantages in the two-cylinder compound engine. It seemed not unreasonable therefore that the use of three or more cylinders should have resulted in the greater efficiency which had been actually obtained from them.

The question of testing the efficiency of the engine separately from that of the boiler had been raised by Mr. Cochrane; and although this subject had been discussed over and over again, it still seemed to require further mentioning. In regard to comparing the indicated horse-power of the engine with the number of pounds of water evaporated from the boiler—or rather, carried from the boiler to the engine, because of course it could not be said that it was all evaporated into steam,—he suggested that the comparison would be more natural, more useful, and more readily understood, if the mechanical horse-power of the boiler were substituted for the weight of water evaporated. If the boiler-pressure in lbs. per square foot were multiplied by the volume of steam in cubic feet generated per minute, and the product were then divided by 33,000, the quotient would be the mechanical horse-power of the boiler, and would afford, he considered, the most accurate and scientific representation that could be had of the power of the boiler. In order to distinguish between the efficiency of the boiler and the efficiency of the engine, it would only be necessary to compare the mechanical horse-power of the boiler with the indicated horse-power of the engine. In this way it would be found, not always, but usually with good engines, that the engine horse-power was actually greater than the boiler mechanical horse-power. Instead of a statement like 15 to 30 lbs. weight of steam used per engine horse-power, it would be found that each boiler mechanical horse-power yielded from $1\frac{1}{4}$ to $2\frac{1}{2}$ engine horse-power; and this mode of expression seemed to him to be more consonant with practical convenience and clearness.*

* In using these terms it is necessary to distinguish between the *mechanical* horse-power of the boiler, as above defined, and the *heat* horse-power of the same boiler. The latter is equal to the number of English heat-units supplied per minute to the water, multiplied by 772 and divided by 33,000; and is generally about fifteen times the boiler mechanical horse-power.

(Professor Smith.)

In regard to the three conditions of efficiency enumerated on page 474 of the paper, he wished to ask whether these were compatible one with another; no doubt they were all desirable. But if the range of temperature were settled in each cylinder, he imagined that this would settle the range of pressure per square inch; and if the ratio of total pressure were settled in order to get equality of stresses, this would give the two ratios of the cylinder areas. These having thus been determined, he did not see how it was possible to design an engine so as to get an equality of horse-power in the three cylinders concurrently with the fulfilment of the two other conditions. If the condition of an equality of *mean* total pressure had been substituted instead of *initial* pressure, then it appeared to him that the two first conditions would have included the third.

Mr. Charles Cochrane wished to remark, in regard to the suggestion made by Professor Smith, that what he himself wanted was to get a complete severance between the performance of the boiler and that of the engine.

Mr. Thomas R. Crampton was sure they must all have been highly pleased with Mr. Wyllie's admirable paper. At the same time, so far as he was concerned, he could not quite follow it. It was going too far he thought from the elementary principles, to which their attention had been brought back by the remarks of Mr. Cochrane as to the quantity of water used per horse-power. As long ago as 1842 he had himself made experiments with a compound engine, in conjunction with the late Mr. Edward Humphrys, and had got one horse-power with 19 lbs. of water, taking no account of the fuel but simply of the water.

In the triple-expansion engine, the object in view was to get a saving by using steam of higher pressure and expanding it a greater number of times. But if instead of beginning with steam of 60 lbs. total pressure and expanding it six times down to 10 lbs., the initial pressure were raised to 120 lbs. and the steam were expanded twelve times, it would be seen that the theoretical gain so obtained was only about 20 per cent. In practice however he had found, on

testing this point in a pumping engine and comparing the water lifted with the indicator diagram, that nearly the whole of the theoretical gain was lost in friction and condensation and other causes; and this loss he thought had not been sufficiently investigated in dealing with expansion engines.

At the present time he had a narrow-gauge locomotive with four adhesion wheels running in regular work, having two equal cylinders on each side, of 6 inches diameter and 9 inches stroke, which worked on cranks opposite to each other or 180° apart; the two cranks were close together sideways on the outside of the same wheel, one being an overhung or return crank. The pair of cylinders on one side of the engine thus worked one of the two driving axles and drove one pair of wheels, while the pair of cylinders on the opposite side of the engine worked the second axle driving the other pair of wheels. The effect was that each pair of cylinders was perfectly balanced, thereby neutralising all strains on the side frames due to the working of the cylinders. In some engines these strains amounted to about 18 tons reciprocating 250 times per minute; and they were the greatest strains to which a locomotive was subject. This was the first instance he believed in which their neutralisation had been practically effected in an engine with four adhesion wheels. The ordinary boiler-pressure was used of about 145 lbs. per square inch. This engine had been altered from an ordinary engine having two cylinders of 7 inches diameter and 14 inches stroke; and on testing each by itself without a train, to ascertain the friction, the altered engine was found to start with 30 per cent. less power than the unaltered. Further exhaustive experiments were being carried out.

Mr. Henry H. West remarked that equality in the range of temperature in each cylinder had been recommended in the paper as one of the important elements of efficiency. This recommendation he thought should be qualified by a consideration of the length of that portion of the stroke through which the range of temperature extended. It appeared to him that, as had been pointed out by Mr.

(Mr. Henry H. West.)

Kirk on another occasion,* the element of time, which came into play in relation to the condensation, should not be lost sight of. If the range of temperature, though in some of the diagrams it might be as much as 70° or 80° Fahr., extended over only a small portion of the stroke, the influence of that range, as change of temperature, could not be so deleterious as it would be if it extended over the whole length of the stroke, as it did in the case of some diagrams.

Mr. E. H. Carbutt said that in the course of the present discussion reference had been made to the use of the corrugated boiler-flues manufactured by Mr. Samson Fox; and there seemed to be a good deal of difference of opinion as to whether all the saving in consumption of fuel, which had been stated to be effected with the triple engines, was due to the engine or to the boiler. It therefore occurred to him to suggest that Mr. Fox might, if possible, make some experiments with one of his boilers, and give the results at the next meeting of the Institution. If he could comply with this suggestion, it would help forward the interests of engineers generally.

Mr. David Greig thought the two-cylinder compound engines referred to in the paper had not received fair play in being worked at only 70 and 75 lbs. pressure, while the triple-expansion engines had been worked at 140 and 150 lbs.; and before making any comparison he considered the two-cylinder engine ought to be worked at the same pressure as the triple-expansion engine. Mr. Cochrane's suggestion about keeping the boiler performance distinct from that of the engine was a most important one, for engineers had not yet made enough experiments upon the actual utilisation of the heat from the coal. For measuring the evaporative power of the boiler, it would not be fair he thought to take merely the weight of the feed-water, because one boiler might prime more than another.

---

* Transactions of the Institution of Naval Architects, 1882; paper by Mr. A. C. Kirk on the Triple-Expansion Engines of the s.s. "Aberdeen."

The 150 lbs. pressure which had now been reached in marine engines could not in his opinion be taken by any means as a limit for future practice; for he was himself working engines every day at 180 lbs., and sometimes at 200 lbs., and had no trouble with them. Beyond 200 lbs. indeed he did experience some trouble; and no doubt before long some arrangement would be arrived at by which steam at 200 lbs. pressure could be worked without difficulty. Possibly four or five cylinders would then be required, instead of three: so that the end was not yet quite reached.

Mr. W. D. Scott-Moncrieff mentioned that his own experience some years ago with regard to expansion in the use of compressed air had been somewhat unique, as he had had to deal with something like 500 lbs. initial pressure. He wished to remark in reference to the indicator diagrams now exhibited, that if in future the triple-engine diagrams were to be made out in the same way, which had been spoken of by Professor Kennedy as being the best that could possibly be carried out in practice, great care should be taken with regard to the character of the theoretical curve with which the actual diagrams were laid out and compared. The theoretical curves here shown appeared to him to be more strictly adiabatic in character than they ought to be in order to serve as the foundation for calculating the theoretical value of the steam. The curve for comparison ought to be the curve of maximum efficiency, allowing for the contraction due to unavoidable thermal losses; and standards might be drawn out for both jacketed and unjacketed cylinders.

He agreed with Mr. Cochrane that the practical question of the interdependence between the boiler and the engine was one which could not long remain on its present unsatisfactory footing. There were elements of the greatest importance which were entirely eliminated, even in a discussion that was supposed, as in the present case, to include all the conditions; and the principal value of the paper depended upon the supposition that identical boilers were being used in comparing the efficiency of the various engines. Looking upon the engine simply as a heat engine was the most

(Mr. W. D. Scott-Moncrieff.)
scientific way of regarding it. The store of heat available in the coal and the speed attained by the ship were the extreme limits of the problem; and it was absolutely necessary that all the intervening conditions should be taken into account, the boiler being obviously as important as any. If this were omitted, the most confusing and contradictory conclusions might be arrived at.

Mr. W. W. Beaumont considered that in fairness to the author it should be borne in mind that marine engineers had to be guided as much by what the shipowners required as by what was to be learnt from the reading of indicator diagrams. There was a great deal, and it was all perfectly true, in what Professor Kennedy had said concerning the quantity of steam that might or might not be used as indicated by the diagrams. But the steamship owners did not care at all about what the diagrams showed; what they wanted to know was for how much coal they could carry a ton of cargo from one port to another. When the results were taken from a set of engines and boilers working day after day over many voyages and thousands of miles, slight inaccuracies as to the quantity of coal might be eliminated; and although for experimental purposes and for questions of thermo-dynamics it would be very much better to know the number of pounds of water used per indicated horse-power, still after all the question was for how much coal could the cargo be carried. It was this consideration by which marine engineers had to be guided in designing engines to satisfy the shipowners, who had found that triple-engine ships worked more profitably than those with the ordinary compound engines. Whether the economy was due to higher pressure or to the use of three cylinders, of the result there was little doubt; and he thought the advantages of the high pressures could not be obtained with less than three cylinders.

With reference to the relative amounts of condensation in the several cylinders, different opinions had been expressed as to which of the three cylinders, if any, should be jacketed. In many instances he knew that the condensation in the high-pressure cylinder of a triple-expansion engine had been found to be much greater than in either of the other two; and when it was remembered that the rate at

which the heat might be carried away would be greater in the cylinder in which there was the highest temperature, such a result seemed not surprising. Whether therefore the requirements in regard to coal consumption could or could not be gathered from the indicator diagrams was a question that depended very much upon the relative rates at which the condensation took place in the several cylinders; and the other question as to the proportions of the several cylinders was also affected by the same consideration.

The President then adjourned the discussion to the next meeting.

MEMOIRS.

James Kennedy was born on 13th January 1797, in the village of Gilmerton, three miles south of Edinburgh. At the age of thirteen he left school and was apprenticed to a millwright near Dalkeith, with whom he remained for five years. He then spent some years at Sir John Hope's collieries at Lasswade, taking charge of the winding and pumping engines; and afterwards worked as a millwright in some cotton mills at Blantyre, near Glasgow. He was next employed by Mr. John Stevenson in fitting water-wheels at the Monkland Steel Works. Thence he went for two years to Lavenoch Hall, near Hamilton, to erect pumping and winding engines, for which the designs and patterns had been made by himself. He next obtained employment at the Lochrin Distillery, Edinburgh, where he substituted a larger engine in place of the small one previously used for grinding malt. While in Edinburgh, he constructed direct-acting marine engines for steam-vessels; one of these was for the s.s. "Emerald Isle" belonging to the St. George's Steam Packet Co., Liverpool, whither he proceeded to superintend its erection. Being there introduced to George Stephenson, who was at that time establishing locomotive works at Newcastle-on-Tyne, he was appointed in 1824 manager of the works, where he remained for eighteen months. During this engagement he planned and erected the engines for a tug on the Tees at Stockton, constructed two pairs of winding engines with vertical drums for hauling loaded wagons up inclines on the Stockton and Darlington Railway, and planned the first three locomotives by which that railway was opened in 1825. Leaving Newcastle at the end of 1825, he returned to Liverpool, and undertook the management of the works of Messrs. Mather and Dixon. Later he became a partner in the firm of Messrs. Bury, Curtis, and Kennedy, of Liverpool, engaged in the construction of locomotive, marine, and stationary engines. The first locomotive built by him

here was the "Dreadnought," employed in the formation of the Liverpool and Manchester Railway in 1829; it had horizontal cylinders working on a crank-shaft which was connected with the driving wheels by pitch chains. In 1830 the second locomotive of his construction, the "Liverpool," was placed on the same line. This was the first engine made in England with horizontal cylinders applied direct to the crank-axle of the driving wheels. The draught was at first obtained by means of a blowing cylinder; but this arrangement not proving successful, a tubular boiler was substituted, in conjunction with a vertical cylindrical fire-box surmounted by a capacious dome. The satisfaction given by a locomotive built by his firm for the Leicester and Swannington Railway resulted in their making also the engines for opening the London and Birmingham Railway. From 1832 to 1834 they sent to America a number of locomotive engines, together with the wheels, axles, and iron-work for wagons and carriages. Having previously constructed marine engines for the early Cunard steamers, in 1837 he built two pairs of non-condensing engines for boats on the Rhône, having locomotive boilers working with 60 lbs. steam pressure per square inch; and in the following year he supplied for the same purpose two pairs of condensing engines, with boilers in which the draught was obtained by an exhausting fan at the bottom of the chimney; the piston-speed was about double that in use at the time in England; and these engines were still in existence at Lyons in 1860. In 1844 he controlled the affairs of Messrs. Thomas Vernon and Son, Liverpool, in the business of iron-shipbuilding, and prepared plans for vessels requiring exceptional strength, in which he introduced iron deck-beams, now universally employed. His death took place on 25th September 1886, at his residence, Cressington Park, near Liverpool, in the ninetieth year of his age. He was a Member of this Institution from the commencement in 1847, and occupied the Presidential chair in the year 1860.

David Thomson was born on 15th November 1816, at Maxton Manse in Roxburghshire, being the son of the parish minister. After receiving a good school education and passing through a

scientific course at Glasgow University, he was apprenticed to Messrs. Claud Girdwood and Co., mechanical engineers, Glasgow; and on the closing of their establishment removed to that of Messrs. Nasmyth Gaskell and Co., Bridgewater Foundry, Patricroft, near Manchester. He was then employed temporarily by the Peninsular and Oriental Steam Navigation Company and other firms, until in 1845, through his acquaintance with the late Mr. Archibald Slate, he was appointed manager of the engineering works of Messrs. William Simpson and Co., London, where he remained for twenty years. When the intake for the supply of the Lambeth Water Works from the river Thames was removed about 1848 to a point near Thames Ditton, above the tide-way of the river, and the water had to be forced thence through a 30-inch main nine miles long to the reservoirs at Brixton and Streatham, the necessary investigations with respect to the pumping arrangements were entrusted to him, in conjunction with Mr. William Pole; and four large double-cylinder engines of 600 aggregate horse-power were designed and constructed in 1852, of which a description was subsequently given to this Institution (Proceedings 1862, pages 242, 259). In connection with these engines he introduced a double-acting bucket-and-plunger pump, the principle of which had been previously indicated by Smeaton in 1759. He afterwards superintended the construction of the South Staffordshire Water Works, as resident engineer at Lichfield. In July 1865 he became manager of the engineering works of Messrs. Richard Moreland and Son, Old Street, London, where he remained till 1877. From 1867 to 1874 he constructed a large number of sluices and other mechanical appliances for the Metropolitan Main Drainage Works, in connection with which he also designed and constructed temporary plant of large capacity, including a lift-pump of 52 inches diameter for lifting the sewage from the low-level into the high-level sewer during the completion of the Abbey Mills pumping-station. In conjunction with Mr. Porter he devised a new form of pump-valve having a free edge of india-rubber, which was first applied to the sewage pumping engines at Crossness, and has since been extensively used for sewage and waterworks purposes. In 1867 he designed and constructed the pumping machinery for the sewage

farm of the Metropolitan Sewage Essex Reclamation Company at Barking Creek. In 1869 he introduced the inverted-cylinder direct-acting rotative pumping engine at the Eastbourne Water Works, which was followed in 1876 by duplicate machinery, and in 1881 by large engines of the same type but with compound tandem cylinders. Similar engines were constructed in 1874 for the Moulsey intake of the Lambeth Water Works; and in 1875 for the Bute docks, Cardiff. For these docks he also constructed the dock gates in 1877; and he applied the principles of Appold's pump to the centrifugal pumps there used, which were fitted with a cover for relieving the pressure from the top of the fan (see Proceedings 1884, pages 234–5). In 1867 he designed and constructed a road-roller weighing 30 tons, having a roller 7½ feet diameter and 6 feet wide, and with an arrangement for rendering the exhaust steam nearly noiseless. In 1876 he constructed for the Leith docks two coal tips, in which the usual tipping cylinder was dispensed with, the tipping being effected by the motion of the main ram. He also designed and constructed a large number of hydraulic appliances, including capstans for Chatham dockyard extension works; and among miscellaneous works were dredgers for Barrow, tanks for submarine cables, power capstans for Devonport dockyard, and a pair of large horizontal engines for Woolwich gun factory. In 1876 he became a director of the Crystal Palace, and devoted much attention to the numerous important engineering works in connection therewith. In 1877 failing health led to his retiring from active duties at Messrs. Moreland's manufactory, although he continued to give occasional assistance there up to September 1881. He died at his residence, Craighead, Belvedere, Kent, on 11th April 1886, at the age of sixty-nine. He became a Member of this Institution in 1879.

INDEX.

1886.

Accounts for year 1885, 8–11.

Adamson, D., Remarks on Triple-Expansion Engines, 519.

Adamson, T. A., elected Member, 1.

Address of President, Jeremiah Head, Esq., at London meeting, 275.—Depression of Trade, 275.—Over-production, 276.—Conditions determining market-prices, 276.—Limitation of production, 277.—Relation of mechanical engineers to over-production, 277.—Facilities for cheap production by improved mechanism, 277.—Illustrations from works visited at recent meetings, 278: cycles, 278; agricultural machinery, 278; steam navvy, 279.—Watch-making, 279.—American Waltham watches, 280.—Swiss watches, 281.—American competition in bridge-building, 281.—Production and consumption, 282.—Foreign competition in neutral markets, 283.—Future effect of exports on national industry, 283: exportation of agricultural machinery, 283; of ships, 284; of coal, 284; of machinery for foreign factories, 285.—Iron and steel works in Spain, 285.—English engineers in foreign works, 285.—Hungarian roller-milling of corn, 286.—Government control of exports, 286.—Conditions determining localisation of trades, 287.—Relation between over-production and mechanical progress, 287.—Influence of wastefulness on depression of trade, 288.—Wastefulness in conducting the business of the state, 288.—Railway rates, 289; cost of making railways, 289.—Dr. Franklin's remarks on taxes, 290.—Losses occurring through strikes, 290.—Pauperism and the poor-law system, 290.—Poor-rates should be national instead of local, 291.—State employment of the otherwise unemployed, 291.—Immoralities causing trade depression, 291.—Relation of over-production to producer and to consumer, 292.—Increased purchasing power of money, 293.—Revival of trade, 293.—Royal Commission on depression of trade and industry, 294.

Rennie, G. B., Vote of thanks to President for Address, 294; main cause of depression in trade is over-production, 294.—Carbutt, E. H., Seconds vote of thanks, 295; cheaper production of manufactured articles, 295; increased taxation, 296.—Head, J., Reply to vote of thanks, 296.

Agricultural Hall, Kensington, 423.

Aisbitt, M. W., elected Member, 270.

Albright, J. F., elected Member, 125.

Anderson, Sir J., memoir, 460.

Anderson, W., Remarks on Compound Locomotives, 401.

Anglo-American Brush Electric-Light Works, 424.

Annual Dinner, 127.

Annual General Meeting, Business, 1.

Annual Report of Council, 3. *See* Council, Annual Report.

Arc Works, Chelmsford, visited at Summer meeting, London, 410, 413–414.

Arsenal, Woolwich, visited at Summer meeting, London, 411, 440–441.

Artificial Draught for boiler furnaces, 380, 395, 489, 498, 499.

Aspinall, J. A. F., Remarks on Autographic Test-Recorder, 89 :— on Compound Locomotives, 391.

Atkey, A. R., elected Graduate, 2.

Auditor, appointment, 20.

Autographic Test-Recorder, *Paper* on an Autographic Test-Recording Apparatus, by J. H. Wicksteed, 27.—Previous reference to diagram-recording apparatus, 27. — Advantages of obtaining diagrams autographically, 28.—Description of autograph diagram, 28.—Record of load, 29.—Description of autographic indicator, 30.—Friction of hydraulic leathers, 31.—Freedom from friction by rotation of ram, 32.—Record of extension, 33.—Interpretation of records, 35.—Area of diagram represents mechanical work of test, 35. — Declining resistance after climax of strength, 36. — Local heating and local extension, 36. — Comparative ductility of samples not identical in shape or proportions, 37.—Diagram of cohesive force of material tested, 38.—Increase in tenacity concurrently with decreasing area, 40.—Summary of successive stages in testing of specimens, 41.—Advantages of autographic record, 42.

Discussion.—Wicksteed, J. H., Exhibited test specimens and diagrams, 62; perfect elasticity and correct scale of indicator spring, 62; base line of diagram, 62; wavering line in diagram at elastic limit, 63.—Kennedy, A. B. W., Difficulty in designing test-recording apparatus, 63; friction of leathers on main ram, 64; elimination of friction of indicator ram by rotation, 64; registration of strains within range of elasticity, 65; description of autographic apparatus used by himself, 65; labour involved in constructing non-autographic diagrams, 67; measure of value of material by mechanical work expended in breaking, 67; exclusion of local extension near place of fracture, 69; comparison of test-pieces of different shapes, 69; manipulation of poise-weight, 69; excess of tensile strength in drilled test-pieces, 69.—Cochrane, C., Enquiry as to effect of shape of material on tensile strength, 70.—Kennedy, A. B. W., Former explanation, 70.—Walker, B., Value of autographic test-recorder for showing quality of steel, 70; friction of hydraulic leathers is uniformly proportional to water

pressure, 71; hydraulic press for testing steel bridge-links, 71.—Unwin, W. C., Steel-yard of testing machine can be kept floating during test, 72; difficulty with very ductile bar, 72; other plans of autographic recording apparatus, 73; objection to taking indication of load from pressure in hydraulic cylinder, 74; adjustments for obtaining uniformity of load scale, 75; arrangement of wire, use of radius-links, and mode of dispensing with compensation, 75; difficulty of determining climax in flat-headed diagram, 77.—Wicksteed, J. H., Prominence of climax in typical diagram, 77.—Unwin, W. C., Measurement of quality of material by mechanical work done up to fracture, or only up to climax of strength, 77; Professor Hartig's results, 78.—Wicksteed, J. H., Stiffness makes up for want of extension, 78.—Unwin, W. C., Results of estimating quality of different materials by comparison of work done up to rupture, 78.—Wicksteed, J. H., Enquired mode of comparison, 79.—Unwin, W. C., Comparison between equal weights of different materials, 79.—Halpin, D., Desirability of magnifying diagram in portion recording extension within elastic limit, 79; objection to manipulation of poise-weight, 80; coefficient of mechanical value, 80; length of test-pieces, 80.—Turner, T., Tensile tests of grooved bars, 81; relation of elongation to diameter of iron and steel bars, 81.—Cochrane, C., Importance of trustworthy testing machine, 82; value of Mr. Bennett's tests, 83; increased tenacity resulting from drilling and from grooving, 83.—Bennett, H. B. S., Use of autographic testing machine at Horseley Iron Works, 84.—Turner, T., Increased tensile strength in drilled bar is due to shortening of length tested, 84.—Smith, R. H., Degree of accuracy in autographic apparatus, 84; freedom from friction by rotation of indicator ram, 85; extension of wire by friction over pulleys, 85; final portion of autographic curve depends on character of testing mechanism, 86; rate of pumping water into hydraulic cylinder, 86.—Wicksteed, J. H., Water is necessarily pumped in at uniform rate, 86.—Smith, R. H., Relative movement of jockey-weight, 87; similar experience in other testing machines, 87; area of autographic diagram is insufficient by itself to represent character of material tested, 88; Wertheim's experiments on increase of volume under tensile stress, 88; apparatus for testing rate of flow in specimens under constant load, 88.—Aspinall, J. A. F., Autographic test-recorder devised by himself, 89; final portion of diagram after climax of strength, 89.—Traill, T. W., Utility of autographic apparatus, 90; length of test specimens, 90; percentage of elongation, 91; more injurious effect of punching in thicker steel plates, 91.—Langley, A. A., Injury to rails by punching, 92; autographic apparatus for recording movements of railway carriages, 92.—Robinson, H., Difference in friction of hydraulic leathers in the testing machine, 92.—Wicksteed, J. H., Difference in diameters, 93.—Carbutt, E. H., Importance of both chemical and

mechanical analysis of iron and steel, 93; loss of strength after reaching the elastic limit, 93.—Wicksteed, J. H., Comparison of grips and pins for holding test-specimens, 94; loss of strength after reaching the elastic limit, 94; measurement of stress by elasticity of straight steel bar or of helical spring, 95; accuracy of load scale produced by spring, 96; friction on wire transmitting extension, 97; use of compensating pulleys, 97; friction of hydraulic leathers in relation to diameter of rams, 98; clips for attaching wire to test-sample, 98; Mr. Aspinall's recording apparatus, 98; practical advantage of perfectly self-acting apparatus, 99; inertia of moving parts, 100; liveliness of indicator, 100.—Head, J., Rapidity of tracing diagram after reaching elastic limit, 100.—Wicksteed, J. H., Rate of motion of pencil, 101; autographic curve is not at any part a function of the machine, 101; uniformity in pulling force, 101; desirability of keeping steel-yard free from motion, 101; adjustments of indicator, 102; proper use of autographic diagrams for indicating qualities of materials, 103.—Sterne, L., Diagrams obtained in punching cold iron, 103.—Head, J., True value of autographic testing machines, 104.

Autumn Meeting, Leeds, 465. — Business, 465.—Opening of Engineering Department of the Yorkshire College, 468.

Bailey, W., elected Member, 270.

Bale, M. P., Motion for alteration in Bye-Law, 20.

Ball Bearings for Cycles, 177, 179, 184. *See* Wheel Load in Cycles.

Batho, W. F., memoir, 261.

Beaumont, W. W., Remarks on Triple-Expansion Engines, 530.

Beckton Gas Works, visited at Summer meeting, London, 411, 442–447.

Belgian Engineers, invitation to Summer meeting, London, 267.—Welcome by President, 268.—Attendance at meeting, 273.—Provincial excursions, 273.

Bennett, H. B. S., Remarks on Autographic Test-Recorder and Tests of Iron and Steel, 84.

Bennett, P. D., decease, 3, 4, 18, 20.—*Paper* on Tensile Tests of Iron and Steel Bars, 44.

Bennison, W. C., elected Associate, 271.

Bicycles, 128. *See* Wheel Load in Cycles.

Blandford, T., elected Member, 125.

Bodden, G., memoir, 461.

Boiler-Furnaces, artificial draught for, 380, 395, 489, 498, 499.

Borodin, A., *Paper* upon Experiments on the Steam-Jacketing and Compounding of Locomotives in Russia, 297.—Remarks on ditto, 363, 403.

Boult, A. J., elected Member, 465.

Bourne, T. J., elected Graduate, 466.

Boys, C. V., Remarks on Wheel Load in Cycles, 162, 170.

Bridge, Cantilevers for Sukkur Bridge, India, 457.
Bright, W., elected Member, 465.
Brook-Fox, F. G., Remarks on Compound Locomotives, 382.
Brounlie, J., elected Graduate, 126.
Brown, A., elected Graduate, 2.
Buckney, T., elected Member, 270.
Budenberg, C. F., elected Graduate, 2.
Buffer-Stop, Hydraulic, for Railways, 105. *See* Hydraulic Buffer-Stop.
Bye-Laws, Alteration in, 20–25.—Bale, M. P., Moved alteration of Bye-Law 22, 20.—Tayler, A. J. W., Seconded motion, 21.—Head, J., Effect of alteration, 21.—Opinion of Council, 22.—Robinson, H., Moved negative of proposal, 23.—Cochrane, C., Seconded negative, 23; issue of brief statement of purport of papers, 23.—Griffiths, J. A., Issue of abstract of papers, 24.—Robinson, H., Members can now get whole of each paper, 24.—Paget, A., Amplification of titles of papers, 24.—Greig, D., Brief account of papers beforehand, 24.—Head, J., Suggestions will be considered, 25.—Motion negatived, 25.

Cairnes, F. E., elected Graduate, 466.
Cambridge, H., elected Member, 125.
Carbutt, E. H., re-elected Vice-President, 17.—Remarks on Autographic Test-Recorder, 93:—on Hydraulic Buffer-Stop, 112.—Vote of thanks to President for Address, 295.—Remarks on Compound Locomotives, 395:—on Triple-Expansion Engines, 528.
Carrick, H., Remarks on Compound Locomotives, 391.
Carver, C., elected Graduate, 271.
Caulfield, W. B., Remarks on Raising a Wreck, 197.
Chalmers, J. R., elected Member, 1.
Chapman, H., Seconded motion for appointment of Auditor, 20.
Childe, R., memoir, 462.
Chittenden, E. B., elected Member, 465.
Clayton, S., elected Member, 465.
Cochrane, C., Remarks on alteration in Bye-Law, 23:—on Autographic Test-Recorder and Tests of Iron and Steel, 70, 82:—on Triple-Expansion Engines, 503, 526.
Cold-Air Machines, 201. *See* Refrigerating Machinery.
Coles, R., elected Member, 1.
Colonial and Indian Exhibition, South Kensington, visited at Summer meeting, London, 410, 411, 426–428.
Colyer, F., Remarks on Refrigerating Machinery, 246.
Compound Locomotives in India, *Paper* on the Working of Compound Locomotives in India, by C. Sandiford, 355.—Conversion to compound

system of two ordinary locomotives on Scinde Punjaub and Delhi Railway, 355.—Particulars of two-cylinder and four-cylinder compound engine, 356.—Resulting economy in fuel, 356, 357.—Comparative expense of alterations, 357.—Coupling rods, 357.—Exhaust from high-pressure cylinders into low-pressure, 358.—Blast, and oil consumption, 358.—General results of compounding in the two engines, 358.—Tractive power required, 362.—Table of comparative trials of fuel in daily train service with ordinary locomotives, not compound, 360–361.

Discussion, 363–409. *See* Compound Locomotives in Russia.

Compound Locomotives in Russia, *Paper* upon Experiments on the Steam-Jacketing and Compounding of Locomotives in Russia, by A. Borodin, 297.—Previous experiments and investigations, 297.—Mode of carrying out present trials, 297.—Part I, Tests made in locomotive testing shop, 298.—Description of testing shop, 298.—Appliances for making observations, 299; for collecting exhaust steam, 299; for direct measurement of feed-water, 301.—Mode of conducting the tests, 301.—Data furnished by observations, 302.—Verification of results, water carried over by steam, 303; consumption of moist steam, 304.—Tests made in 1882 with ordinary locomotive A 22 steam-jacketed, 305.—Table 1, details of seven different steam distributions, 307.—Table 2, results of tests, 308–311.—Utility of steam-jacket completely demonstrated, 313.—Table 3, steam consumption with and without steam-jacket, 314.—Analysis of indicator diagrams with respect to utility of steam-jacket, 315.—Selection of average diagrams, and calculations therefrom, 316.—Threefold effect of steam-jacket, 317.—Table 4, results of analysis of indicator diagrams, 318.—Tests made in 1881 with ordinary locomotive A 21 not steam-jacketed, 319.—Table 5, test with later cut-off, 319.—Table 6, test with earlier cut-off, 320.—Benefit of steam-jacket confirmed by unjacketed experiments, 320.—Cylinders of too large size are unfavourable to economy of steam, 321.—Tests made in 1881 with compound locomotive A 7 steam-jacketed, 321.—Table 7, steam consumption in compound engine when steam-jackets were not working, 322.—Economy in steam-consumption by compound locomotive, 323.—Part II, Trials made with experimental trains, 324.—Appliances for observations on engine and tender, 324.—Mode of conducting the tests, 325.—Table 8, details of valve-motions, 326–327.—Points noted during tests, 328.—Calculation of work done, 329.—Consumption of water and fuel per I.H.P. per hour, 330.—Effect of regulator opening on initial steam-pressure in cylinders, 331.—Evaporation of water per pound of wood, 331.—Table 9, details of running, 332–333.—Comparative consumption of water and fuel in compound and ordinary locomotives expanding equally, 334.—Table 10, water consumption in ordinary and compound locomotive, 336–337.—Comparative economy in

compound locomotive, 338.—Comparative work done by compound and ordinary locomotives with equal consumption of water and fuel, 338; Table 11, 339.—Comparative consumption of water and fuel in compound and ordinary locomotives doing equal work, 340; Table 12, 340.—Proportion of work done in small and large cylinder of compound locomotive, 341; Table 13, 342.—Effect of jackets on consumption of steam, 343. — Imperfect draining of jackets, 344. — Advantageous peculiarities of compound locomotive, 344.—Experiments made in 1881–82 with compound and ordinary locomotives while running, 345; Table 14, 346.—Part III, Consumption of fuel in regular working of compound and ordinary locomotives, 347.—Table 15, mean consumption of wood during five years, 347.—Part IV, General conclusions, 349.—Table 16, consumption of steam in ordinary and compound locomotives without steam-jackets, 348.—Table 17, ordinary locomotive A 22 without steam-jackets, 349.—Table 18, compound locomotive without steam-jackets, 351. —Most advantageous distribution of steam, 351.—Table 19, tests made in 1883 with compound locomotive in testing shed, 352. — Economy produced by steam-jackets and by compound system, 352–353.—Undoubted advantage of compound locomotive, 354.—Advantages of a testing shop properly fitted up, 354.

Discussion.—Borodin, A., Agreement of results from these trials with those of other experimenters, 363; proportionate work done in small cylinder of compound engine, 363.—Halpin, D., Scope of paper, 363; effect produced on indicator diagrams by long and bent indicator pipes, 364; steam-jackets must act as condensers, 365; steam-trap for draining jackets, 365; draining of jackets by auxiliary injector, 365; by ordinary injector, 366; three elements affecting the value of steam-jackets, 366; ratio of jacket surface to cylinder volume, 367; projecting ribs round outside of cylinder barrel for increasing the transmission of heat from jacket, 368; friction brake for absorbing whole power of engine, 368; cooling of brake-wheel with cold water, 369; Royal Agricultural Society's trials, 370; drop in steam-pressure from boiler to cylinders, 370; too high velocity of steam in pipes, 371.—Davey, H., Desirability of experiments for determining value of steam-jacket, 371; steam-jackets discontinued on compound mining engines, 372; greater value of jacket on high-pressure cylinder than on low-pressure, 373.—Mallet, A., Two cylinders only are preferable for compound locomotives, 373; ratio of cylinder capacities, 374; arrangement for independent working of the two cylinders, 374; four-cylinder compound locomotive, 374; high-speed express engine with triple expansion in four cylinders, 375.—Kennedy, A. B. W., Questions as to details of experiments, 376; indicator diagrams affected by arrangement of indicator pipes, 376; amount of condensation

in steam-jackets, 377; difference of heat in jacket steam and cylinder steam, 377; jackets should be drained automatically, 378; arrangement for obviating error in friction brake, 378.—Rich, W. E., Steam-jacketing of cylinders of compound locomotives, 378; economy arising from jackets, 379; errors resulting from long indicator pipes, 380; use of small fan for blowing the fire, 380; equalisation of work in both cylinders of compound engine, 381.—Stévart, A., Greater number of facts desirable for determining value of compound system in locomotives, 381. — Brook-Fox, F. G., Importance of fuel economy on Indian railways, 382.—Ryan, J., Limit to extent of steam-jacketing, 382; flow of heat through wall of ribbed cylinder, 383; ribs are disadvantageous, 384; flow of heat depends on difference of temperature, 384; stoves for warming with ribbed surfaces are not analogous, 384; cause of diversity in results of experiments on steam-jackets, 385; advantage of jackets in slow-working engines with high expansion, 385; use of large jackets, 385; difference between economy in steam and in fuel in compound engine, 386; diminution in initial pressure in cylinder is due to closing of regulator, 386; importance of recording anomalous results in experiments, 387.—Vinçotte, R., Proper draining of steam-jackets, 387; objection to steam-trap acting by expansion, 387; application of injector for draining jackets, 387; flow of heat through cylinder wall, 388; effect of long indicator pipes upon indicator diagrams, 389.—Greig, D., Important economy from compounding of portable and traction engines, 389; value of steam-jacketing depends on piston-speed, 389; temperature of steam must be kept up in low-pressure cylinder, 390; economy from compounding or steam-jacketing should be the same in steam as in fuel, 390.—Urquhart, T., Mode of supplying steam to jackets, 390; cylinders of too large size, 390; conflicting opinions as to profit from compounding of locomotives, 391; conditions essential in a compound locomotive, 391.—Carrick, H., Fuel economy on Indian railways, 391; importance of simplicity in compounding of locomotives, 391.—Aspinall, J. A. F., Experiments made in locomotive testing shed are less valuable than actual work done in running, 391; facility for changing engines from compound to non-compound or conversely, 392; advantage of Indian wider gauge, 392; fuel economy on English lines, 393; size of steam-pipes, 393. — Riches, T. H., Fuel consumption in Indian compound locomotives, 394; float-valve for draining steam-pipes, 394; use of fan for creating forced draught in locomotive, 395.—Carbutt, E. H., Necessity of railways for development of India, 395; importance of reducing cost of working, 396; exportation of grain from India, 396. — Crampton, T. R., Commercial aspect of expansion, 397; early application of steam-jacketing to locomotives, 397; suggestion of marine boiler for locomotive use, 397.—Walker, B., Early

experiments proving value of steam-jacketing, 398; value of compounding begins at low boiler-pressure, 398; low-pressure cylinder should receive steam as hot as possible, 399; testing of engines by raising and lowering of weights, 399.—Halpin, D., Effect of compounding upon stresses on crank-axle, 399; waste of power in coupled engines, 400; uniformity of power impossible with only two cylinders in compound locomotive, 400; cost of fuel and burning of wood in Indian locomotives, 400; deterioration of coal during transport to India, 400; injector arrangement for draining steam-jackets, 401.—Anderson, W., Carnot's doctrine of efficiency of heat engines, 401; theoretical duty of simple and compound locomotives, 401; effect of steam-jacket on duty of steam within cylinder, 402; advantage of steam-jacket, and of compound expansion, 402.—Borodin, A., Jacketing of cylinders, and discharge of condensed water from jackets, and measurement of feed-water in train-trials, 403; arrangement of indicator pipes, and influence on indicator diagrams, 403; mode of draining steam-jackets, 404; difference between jackets and condensers, 405; boiler-pressure in train-trials, 405; reduction of initial pressure in cylinders is due to closing of regulator, 406; steam-jackets supplied direct from boiler, 406; proportion of heat lost by external cooling, 406; Carnot's principle, and probable cause of economy in compound engines, 407; advantage of locomotive testing shed, 407; uncertainty about fuel-consumption in locomotives, 408.—Sandiford, C., Actual consumption of fuel in Indian compound locomotives, 408; loss of power due to coupling-rods is small, 408.—Head, J., Experiments for determining value of steam-jacket, 409.

Conyers, S. W., elected Graduate, 271.

Council, Annual Report, 3.—Number of Members, 3.—Transferences, deceases, 3.—Resignations, &c., 4.—Financial statement, 4, 8–11.—Research, 5.—Donations to Library, 5, 12–17.—List of Meetings, and Papers, 6.—Attendances at meetings, 6.—Summer meeting and Autumn meeting, 1885, 6, 7.—Summer meeting, London, 1886, 7.

Discussion.—Head, J., Financial position of Institution, 17; moved adoption of Report of Council, 17.—Motion carried, 17.

Council for 1886, v, 17–19.—Election, 17, 18.—Decease of Mr. P. D. Bennett, 4, 18, 20.—Appointment, 18.—Retiring list, 466.—Nominations for 1887, 467.

Crampton, T. R., Remarks on Compound Locomotives, 396:—on Triple-Expansion Engines, 526.

Crossness Sewage Works, visited at Summer meeting, London, 412, 452–456.

Cryer, T., elected Member, 270.

Cycles, Distribution of Wheel Load in Cycles, 128. *See* Wheel Load in Cycles.

Dale, T., elected Member, 125.

Davey, H., Remarks on Compound Locomotives, 371.

Dayson, W. O., elected Member, 125.
Denny, W., re-elected Member of Council, 18.
Depression of Trade, 275. *See* Address of President.
Dixon, R., elected Member, 1.
Dobson, B. A., re-elected Member of Council, 18.—Remarks on Hydraulic Buffer-Stop, 111.
Docks, refrigerating arrangements at London and St. Katharine Docks, 242, 411. *See* Refrigerating Machinery.
Docks, Royal Victoria and Albert, 411, 447–450. — London Docks and St. Katharine Docks, 450.—Tilbury Docks, 411, 450–452.
Donations to Library in 1885, 12–17.
Douglass, Sir J. N., re-elected Member of Council, 18.—Remarks on Hydraulic Buffer-Stop, 114.
Doxford, C. D., elected Member, 465.
Drilling and Punching. *See* Tests of Iron and Steel.
Druitt, T., Treasurer, decease, 271.
Drummond, D., elected Member, 1.
Duncan, N., elected Member, 1.
Duvall, C. A., elected Graduate, 466.
Dynamometer. *See* Friction Brake.

Ede, F. J., elected Member, 270.
Election, Council, 17, 18.—Members, 1, 125, 270, 465.
Electric-Lighting Installations, Colonial and Indian Exhibition, &c., 411, 412, 426–427.
Electric-Light Works, visited at Summer meeting, London. Anglo-American Brush, 424. Chelmsford, 410, 413–414.
Enfield Small-Arms Factory, visited at Summer meeting, London, 410, 428–440.
Engines, Triple-Expansion Marine, 473. *See* Triple-Expansion Engines.
Evaporation of Liquids, 241. *See* Refrigerating Machinery.
Excursions at Summer meeting, London, 410–459. By Belgian Engineers, 273.
Exhibition, Colonial and Indian, South Kensington, visited at Summer meeting, London, 410, 411, 426–428.

Fisher, H., elected Associate, 2.
Flannery, J. F., Remarks on Hydraulic Buffer-Stop, 115.
Folger, W. M., elected Member, 465.
Food Preservation by Cold, 232, 242, 251, 256, 258. *See* Refrigerating Machinery.
Forced Combustion, 380, 395, 489, 498, 499.
Foster, F., elected Member, 270.

Foundling Hospital, London, new sanitary works, 425.
Freezing Mixtures, 239–240. *See* Refrigerating Machinery.
Friction Brake, cooled by water, 369, 378.
Fulton, A. R. W., elected Member, 270.

Gas Works, Beckton, visited at Summer meeting, London, 411, 442-447.
Goods Stations. London and North Western Railway, Broad Street, London. 422. Midland Railway, Whitecross Street, London, 422.
Goodwin, A., Jun., Remarks on Wheel Load in Cycles, 179.
Gorman, W. A., Remarks on Raising a Wreck, 197 :—on Refrigerating Machinery, 249.
Grant, P., elected Graduate, 2.
Great Eastern Railway Works, Stratford, 419.
Greig, D., re-elected Vice-President, 17.—Remarks on alteration in Bye-Law. 24 :—on Compound Locomotives, 389 :—on Triple-Expansion Engines, 528.
Greiner, A., Reply to President's welcome at Summer meeting, London, 269.
Griffiths, J. A., Remarks on alteration in Bye-Law, 24.—*Paper* on the Distribution of the Wheel Load in Cycles, 128.—Remarks on ditto, 162, 180.
Grove, D., elected Member, 125.
Gun, Maxim Automatic Machine-Gun Works, 417.
Guy, C. W., elected Member, 1.

Hackworth's Valve-Gear, 519, 522.
Hall, W. J., elected Member, 270.
Hall, W. S., Remarks on Refrigerating Machinery, 260.
Halpin, D., Remarks on Autographic Test-Recorder, 79 :—on Raising a Wreck, 196 :—on Refrigerating Machinery, 252 :—on Compound Locomotives, 363, 399.
Halsey, W. S., elected Graduate, 126.
Hanbury, J. J., elected Member, 1.
Harrison, J., Remarks on Refrigerating Machinery, 250.
Harvey, J. B., elected Member, 125.
Head, J., re-elected President, 17.— Remarks on Annual Report of Council, 17 :—on re-election as President, 19 :—on appointment of Auditor, 20 :—on alteration in Bye-law, 21, 24 :—on Autographic Test-Recorder and Tests of Iron and Steel, 100, 103 :—on Hydraulic Buffer-Stop, 119 :—on Wheel Load in Cycles, 185 :—on Raising a Wreck, 200 :—on Refrigerating Machinery, 260.—Introductory remarks and welcome at Summer meeting, London, 267.—Remarks on appointment of Treasurer, 271.—*Address* at London meeting, 275; *see* Address. — Reply to vote of thanks for Address, 296.—Remarks on Compound Locomotives, 409 :—at opening

of Engineering Department of Yorkshire College, Leeds, 469: — on Triple-Expansion Engines, 497, 531.

Hilton, C. W., elected Member, 465.

Holden, J., elected Member, 465.

Holdsworth, F. M., elected Graduate, 466.

Hollis, C. W., elected Member, 125.

Hopper, W., decease, 3.—Memoir, 121.

Hosgood, J. H., elected Graduate, 126.

Hunter, J., elected Member, 1.

Hydraulic Buffer-Stop, *Paper* on a Hydraulic Buffer-Stop for Railways, by A. A. Langley, 105. — Object and advantages, 105. — Construction of hydraulic cylinders and pistons, 105.—Tapering strips for maintaining uniform resistance throughout stroke, 106. — Length of stroke, 106.—Fixed stop, 107.—Counterweights for drawing the pistons forwards again after impact, 107.—Body of buffer-stop, 107.—Air as a resisting medium, 108.—Results of trials of hydraulic buffer-stops, 108.—Cost, maintenance, and space, 108.—Length of stroke, 109.—Theory of action, 109.—Hydraulic buffer-stops now in use, 110.

Discussion.—Langley, A. A., Resistance offered by hydraulic buffer-stop, 110.—Tower, B., Length of stroke independent of speed, 111.—Dobson, B. A., Piston-rods remain closed up when carriages are left standing against them, 111.—Tomlinson, J., Experience with ordinary fixed stops, 111; hydraulic stop remains closed up until obstruction is removed, 112.—Carbutt, E. H., Utility of hydraulic stops in terminal stations, 112. — Walker, B., Hydraulic buffer for controlling recoil of guns, 113; hydraulic control of steam-engine, 114. — Douglass, Sir J. N., Hydraulic buffer-stop for gun recoil and railway trains, 114.—Smith, R. H., Shock upon chain attached to counterweight, 114.—Sterne, L., Objection to overhanging weight in projecting buffer-stops with considerable stroke, 115; experience with pneumatic buffer-stop, 115.—Flannery, J. F., Absence of recoil in hydraulic buffer-stop, 115.—Wilmer, H., Efficiency of hydraulic buffer-stops, 116; pressure of water in cylinders, 116; maintenance of proper efficiency, 117; absence of recoil, 117.—Robinson, H., Hydraulic power for controlling steam starting gear in marine engines, 117. — Langley, A. A., Length of stroke independent of speed, 117; stops remaining closed up, 118; speed of running into stops experimentally, 118; damage to fixed buffer-stops, 118; chain attached to counterweight, 118.—Head, J., Gauge-plates for regulating size of orifices in pistons, 119.—Langley, A. A., Size of orifices ascertained by trial, 119.—Head, J., Necessity for efficient buffer-stops, 119; hydraulic stops for gun-carriages, 119.

Hydraulic Power Works, London, 417.

Ice-Making Machinery, 201. *See* Refrigerating Machinery.
Indicator Diagrams, effect of long pipes on indicator diagrams, 364, 376, 380, 388, 403.
Industrial Dwellings, 425.
Iron and Steel, Tensile Tests, 44. *See* Tests of Iron and Steel.

Jack, A., memoir, 462.
Jackson, T., elected Member, 1.
Jewell, H. W., elected Member, 270.
Johnson, W., elected Member, 465.

Kennedy, A. B. W., re-elected Member of Council, 18.—Remarks on Autographic Test-Recorder and Tests of Iron and Steel, 63, 69, 70 :—on Compound Locomotives, 375 :—on Triple-Expansion Engines, 504.
Kennedy, J., memoir, 532.
Knight, C. A., elected Member, 271.

Langley, A. A., Remarks on Autographic Test-Recorder and Tests of Iron and Steel, 92.—*Paper* on a Hydraulic Buffer-Stop for Railways, 105.—Remarks on ditto, 110, 117, 119.
Leather, J. T., memoir, 262.
Lee, C. E., elected Member, 271.
Leeds Autumn Meeting, 465. *See* Autumn Meeting.
Lewis, W. T., Jun., elected Graduate, 466.
Library, Donations in 1885, 12–17.
Liége University, invitation to Belgian Engineers for Summer meeting, London, 267.
Lightfoot, T. B., *Paper* on Refrigerating and Ice-Making Machinery and Appliances, 201.—Remarks on ditto, 242, 256.
Livsey, J. E., elected Member, 271.
Locomotives, Compound. *See* Compound Locomotives.
London and North Western Railway Goods Station, Broad Street, London, 422.
London Chatham and Dover Railway Locomotive Works, 420.
London Summer Meeting, 267.—Welcome to Belgian visitors, 268.—Business, 270.—Appointment of Treasurer, 271.—Votes of thanks, 273.—Excursions, &c., 273, 410.
London Works, visited at Summer meeting, 410–459.
London Yard Iron Works, Poplar, visited at Summer meeting, London, 412, 457–459.
Lucy, W. T., elected Graduate, 2.

Mackenzie, K. R., elected Associate, 466.
MacLean, A. S., elected Member, 271.
Mair, J. G., Motion for appointment of Auditor, 20.
Mallet, A., Remarks on Compound Locomotives, 373.
Marine Engines, Triple-Expansion, 473. *See* Triple-Expansion Engines.
Marquis of Ripon, Remarks at opening of Engineering Department of Yorkshire College, Leeds, 468.
Marsland, L. W., Remarks on Wheel Load in Cycles, 172.
Marten, E. B., re-elected Member of Council, 18.
Martin, E. P., appointed Member of Council, 18.
Martin, W. H., elected Member, 1.
Martindale, Col. B. H., Remarks on Refrigerating Machinery, 242.
Matthews, R., elected Member, 125.
Mattos, A. G. de, elected Graduate, 466.
Maxim Automatic Machine-Gun Works, 417.
McLean, R. A., appointed to audit Institution accounts, 20.
Meetings, 1886, Annual General, 1.—Spring, 125.—Summer, 267.—Autumn, 465.
Memoirs of Members recently deceased, 121–3, 261–6, 460–4, 532–5.
Midelton, T., elected Member, 125.
Midland Railway Goods Station, Whitecross Street, London, 422.
Mill for crushing Gold Quartz, 411, 427–428.
Millar, H. L., appointed Treasurer, 272.
Miller, J. S., elected Member, 271.
Mint, Royal, visited at Summer meeting, London, 410, 413.
Morison, D. B., Remarks on Triple-Expansion Engines, 497, 503.
Mountain, W. C., elected Member, 125.
Mudd, T., Remarks on Triple-Expansion Engines, 510.

Newton, H. E., elected Associate, 466.
Noakes, T. J., elected Member, 1.
Norris, M. O., decease, 4.—Memoir, 121.
North London Iron Works, 425.

Officers. *See* Council.
Ogle, P. J., elected Member, 271.
Owen, T. H., elected Member, 271.

Paget, A., Remarks on alteration in Bye-Law, 24:—on Wheel Load in Cycles 179.
Parker, W., Remarks on Triple-Expansion Engines, 499.
Parry, A., elected Member, 125.
Passmore, F. B., elected Member, 1.

Pattinson, J., memoir, 463.
Peacock, W. J. P., elected Associate, 271.
Pollock, J., elected Member, 1.
Pottery, Lambeth, visited at Summer meeting, London, 410, 414–416.
Powell, T., Remarks on Refrigerating Machinery, 253.
President's Address at Summer meeting, London, 275. *See* Address of President.
Price-Williams, R., Remarks on Refrigerating Machinery, 250.
Price-Williams, S. W., elected Graduate, 466.
Punching and Drilling. *See* Tests of Iron and Steel.

Quartz Mill, Queensland, for crushing gold quartz, 411, 427–428.

Railway Buffer-Stop, Hydraulic, 105. *See* Hydraulic Buffer-Stop.
Raising a Wreck, *Paper* on the Raising of the Wrecked Steamship "Peer of the Realm," by T. W. Wailes, 189.—Position and details of wreck, 189.—Treatment of after part of vessel, and of space amidships, 189.—Platforming of fore part over coal cargo in hull, 190.—Preparations, and tides, 190.—Construction and fixing of platform in fore part, 191.—Use of cement for making water-tight joints, 191.—Pumping arrangement, 192.—Process of raising and towing, 192.—Condition of wreck, and subsequent repairs, 193.
Discussion.—Wailes, T. W., Details of difficulties encountered, 194; minimum freeboard, 194; salvage tugboat with pumping gear, 195.—Halpin, D., Excellence of arrangements, 196; precarious nature of salvage operations, 196.—Tomlinson, J., Cost of operation, 197.—Gorman, W. A., Employment of diver, 197; use of cement, 197.—Caulfield, W. B., Platforming always difficult and often impossible, 197; caulking without cement, 198; size of pumps, 198.—Wailes, T. W., Prevention of leakage by cement, 198; objection to employment of diver, 199; size of pumps, 199; cost of operation, 199.—Head, J., Importance of wreck-raising operations, 200.
Ransome, J. E., elected Member, 125.
Ransome, R. C., memoir, 122.
Raven, H. B., elected Associate, 466.
Ravenhill, J. R., Seconded motion for appointment of Treasurer, 272.
Refrigerating Machinery, *Paper* on Refrigerating and Ice-making Machinery and Appliances, by T. B. Lightfoot, 201.—Apparatus for abstracting heat by the rapid melting of a solid, 202.—Use of calcium chloride by Sir William Siemens, 203.—Use of ammonium nitrate in Toselli machine, 203; and in American machine, 203.—Extended form of Sir William Siemens' apparatus, 204.—Machinery and apparatus for abstracting heat by the evaporation of a more or less volatile

LIQUID, 205.—Vacuum process, 205; Carré's machine, 206; Windhausen's, 206; production of clear ice, 208; details of working and cost, 208; Harrison's apparatus, 209.—Compression process, 210; early machine by Hague and Perkins, 210; Harrison's ether apparatus, 211; cans or moulds for ice, 212; cell system, 213; production of transparent ice, 213; expenditure of mechanical work in machine, 214; results of actual experiment, 214; employment of methylic ether by Tellier, 215; of sulphur dioxide by Pictet, 215; of anhydrous ammonia, 216; difficulty from leakage in ammonia compression machines, 216; glycerine as a lubricant, 216; selection of brine that will not congeal, 217; cost of working, 217; results of test, 218.—Absorption process, 218; Carré's machine, 218; Reece's, with improvements by Stanley, and by Pontifex and Wood, 219; mode of action, 220; comparison of absorption system and compression, 220; cost of ice production by absorption, 221.—Binary absorption system, 221; Mort and Nicolle's ammonia apparatus, 222; De Motay and Rossi's ethylo-sulphurous dioxide, 222; Pictet's liquid, 223.—MACHINERY BY WHICH A GAS IS COMPRESSED, PARTIALLY COOLED WHILE UNDER COMPRESSION, AND FURTHER COOLED BY SUBSEQUENT EXPANSION, 223.—Physical laws relating to permanent gases, 223.—Adiabatic expansion and compression, 224.—Moisture contained in air, 225.—Special air-drying apparatus can be dispensed with, 226.—Hall's cold-air machine, 227.—Haslam's dry-air refrigerator, 227.—Author's horizontal dry-air refrigerator, 228; vertical machine, 229; power expended, 230.—Applications of refrigerating machines, 231.—Preservation of food by dry-air refrigerators, 232; by evaporation of volatile liquid, 233.—Means adopted for freezing and preservation of meat, 233.—Capacity of machine, 234.—Storage of frozen meat, 234.—Dry-air machine combined with gas engine, 235.—Ventilation and cooling of ships' holds, 235.—Refrigerating plant on board ship, 235.—Fish preservation, and cooling of chocolate, 236.—Freezing of running ground in Stockholm tunnel, 236; in sinking of wells and colliery shafts, 238.—Table of freezing mixtures, 239–240.—Table of evaporation of liquids, 241.

Discussion.—Lightfoot, T. B., Model of cold-air machine, 242; Haslam's dry-air refrigerator, 242.—Martindale, Col. B. H., Refrigerating arrangements at London and St. Katharine Docks, 242; capacity and construction of storage chambers, 243; snow in air-trunks, 243; boilers 244; results of experience at stores, 244; rise of temperature in air, 245; coal consumption, and cold-air supply, 245; employment of chemicals, 246.—Colyer, F., Harrison's ether machine, 246; cooling water, and consumption and price of coal, 246; relative advantages of ether machines and ammonia machines, 247; results obtained, 248; leakage in ammonia compression machines, 249; air-cooling in large open rooms, 249.—

Gorman, W. A., Ether machine, 249.—Harrison, J., Latent heat of vaporisation of ammonia and of sulphuric ether, 250; equal efficiency of refrigerating agents, 250.—Price-Williams, R., Cost of ice-production by different processes, 250; food preservation on board ship, 251; cooling of berths, 251; setting of mortar in Stockholm tunnel, 252.—Halpin, D., Insulation of cooled chambers, 252; cork as a non-conductor, 252.—Schönheyder, W., Place of admission of cold air into chamber, 253.—Powell, T., Improvements in Windhausen vacuum machines, 254; production of transparent ice, 254; continuous circulation of sulphuric acid, 255; cost of working, 255; applications of machine, 256.—Lightfoot, T. B., Capacities of refrigerating machines, 256; coal consumption, 256; air cooling in large rooms, 257; variation of heat of vaporisation with pressure, 258; cost of ice-making, 258; freezing of meat, 258; snow in storage chamber, 259; setting of cement in Stockholm tunnel, 259; cork as a non-conductor, 259; Windhausen vacuum process, 259.—Hall, W. S., Setting of brickwork in Stockholm tunnel, 260.

Rennie, G. B., Vote of thanks to President for Address, 294.

Report of Council, 3. *See* Council, Annual Report.

Rich, W. E., Remarks on Compound Locomotives, 379.

Riches, T. H., Remarks on Compound Locomotives, 394.

Ripon, Marquis of, K.G., Remarks at opening of Engineering Department of Yorkshire College, Leeds, 468.

Robinson, H., Remarks on alteration in Bye-Law, 23, 24:—on Autographic Test-Recorder, 92:—on Hydraulic Buffer-Stop, 117.

Robinson, J. (Cardiff), elected Member, 125.

Rules of Institution. *See* Bye-Laws.

Ryan, J., Remarks on Compound Locomotives, 382.

Sandford, H., elected Member, 126.

Sandiford, C., *Paper* on the Working of Compound Locomotives in India, 355.—Remarks on ditto, 408.

Sanitary Works, Foundling Hospital, London, 425.

Scholes, W. H., elected Member, 126.

Schönheyder, W., Remarks on Refrigerating Machinery, 253.

Schurr, A. E., elected Member, 465.

Scott, D., memoir, 263.

Scott, J., elected Member, 126.

Scott-Moncrieff, W. D., Remarks on Triple-Expansion Engines, 529.

Seddon, R. B., elected Member, 271.

Sewage Works, Crossness, visited at Summer meeting, London, 412, 452–456.

Shaw, W. T., Remarks on Wheel Load in Cycles, 169, 180.

Ship, Raising of the Wrecked Steamship "Peer of the Realm," 189. *See* Raising a Wreck.

Silcock, C. W., elected Graduate, 126.
Small, J. M., elected Member, 126.
Small-Arms Factory, Enfield, visited at Summer meeting, London, 410, 428–440.
Smith, R. A., elected Member, 2.
Smith, R. H., Remarks on Autographic Test-Recorder, 84, 86 :—on Hydraulic Buffer-Stop, 114 :—on Triple-Expansion Engines, 524.
Snowdon, F. S., elected Member, 2.
Soper, W., Remarks on Wheel Load in Cycles, 172.
Spring Meeting, Business, 125.
Steam-Jackets. *See* Compound Locomotives. *See* Triple-Expansion Engines.
Steamship, Raising of the Wrecked Steamship "Peer of the Realm," 189. *See* Raising a Wreck.
Steel and Iron, Tensile Tests, 44. *See* Tests of Iron and Steel.
Sterne, L., Remarks on Autographic Test-Recorder, 103 :—on Hydraulic Buffer-Stop, 115 :—on appointment of Treasurer, 271.
Stévart, A., Remarks on Compound Locomotives, 381.
Stoney, F. G. M., Remarks on Wheel Load in Cycles, 175.
Stop, Hydraulic Buffer-Stop for Railways, 105. *See* Hydraulic Buffer-Stop.
Stumore, F., elected Associate, 466.
Sukkur Bridge Cantilevers, 457.
Summer Meeting, London, 267. *See* London Summer Meeting.

Tayler, A. J. W., Seconded motion for alteration in Bye-Law, 21.
Tensile Tests of Iron and Steel Bars, 44. *See* Tests of Iron and Steel.
Testing Machine, with autographic recorder, 27. *See* Autographic Test-Recorder.
Test Recorder, Autographic, 27. *See* Autographic Test-Recorder.
Tests of Iron and Steel, *Paper* on Tensile Tests of Iron and Steel Bars, by P. D. Bennett, 44.—Principal object in making these tests, 44.—Table 1, tensile tests of flat iron bars, with drilled or punched hole, 44, 48–49.—Table 2, tensile tests of flat steel bars, with drilled or punched hole, 45, 50–51.—Table 3, tensile tests of flat iron bars, with drilled or punched hole filled with rivet, 45, 52–53.—Table 4, tensile tests of flat steel bars, with drilled or punched hole filled with rivet, 46, 54–55.—Conclusion from four Tables 1–4, 46.—Table 5, tensile tests of round iron bars, turned down to different diameters and lengths, 46, 56–57.—Table 6, tensile tests of flat steel bars, pulled by grips or by pins, 47, 58–59.—Table 7, tensile tests of flat steel bars, with different lengths of part tested, 47, 60–61.
Discussion, 62–104. *See* Autographic Test-Recorder.
Thomson, D., memoir, 533.
Tilbury Docks, visited at Summer meeting, London, 411, 450–452.

Tipping, H., elected Member, 271.

Tomlinson, J., re-elected Vice-President, 17.—Remarks on Hydraulic Buffer-Stop, 111:—on Raising a Wreck, 196.

Tower, B., Remarks on Hydraulic Buffer-Stop, 111.

Towne, H. R., elected Member, 271.

Trade Depression, 275. *See* Address of President.

Traill, T. W., Remarks on Autographic Test-Recorder and Tests of Iron and Steel, 90.

Treasurer, decease, 271.—Appointment, 272.

Tresca, H., decease, 4.

Trew, J. B., elected Member, 465.

Tricycles, 128. *See* Wheel Load in Cycles.

Triple-Expansion Engines, *Paper* on Triple-Expansion Marine Engines, by R. Wyllie, 473.—High-pressure triple-expansion engine successfully rivals double-expansion compound, 473.—Positions of three cylinders, 473.—General conditions of efficiency, 474.—Steam-jackets, 474; advantage of fitting cylinders with independent liners, 475.—Cylinder ratios, 475.—Steam velocities, 476.—Piston-valves, 476.—Low-pressure cylinder, 477.—Contracted or indirect passages in high-pressure and intermediate cylinders, 477.—Cut-off, 477.—Speed of revolution, 478.—Sequence of cranks, 479.—Number of cranks, 480.—Conversion of two-cylinder compounds into triple-expansion engines, 480.—Advantages of three-crank engines, 482.—Twisting moment on crank-shaft, 482.—Length of engine-room is not increased for three-crank engines, 482.—Valve gear, requirements, 483; four principal kinds, 483.—Single-eccentric sliding-block gear, 483.—Swinging-link gear, 483.—Practical results from triple-expansion engines, 484.—Table 1, three days' log of triple-expansion engines in "Para," 484, 492–496.—Table 2, comparative results from three similar steamers with compound and with triple-expansion engines, 485.—Table 3, ditto from another similar trio of steamers, 486.—Triple engines of "African" and "Shakspear," 486.—Compound and triple engines of "Anglian," 487.—Ditto of "Lusitania," 488.—Triple-expansion engines of "Stella," 489.—Artificial draught for boiler-furnaces, 489.—Memorandum respecting diagrams, 490.—Table 1, three days' log of triple-expansion engines in "Para," 492–496.

Discussion.—Morison, D. B., Scope of paper, 497; care required in taking indicator diagrams, 497; difficulty in obtaining true diagram from high-pressure cylinder, 498; diagrams from engines of "Para," and of "Kaisow," 498; engineer's log from "Stella," 498; application of artificial draught, 498; corrugated flues for boilers, 499.—Parker, W., Triple-expansion engine is the engine of the future, 499; fuel economy and forced combustion, 499; practical results obtained from steamers fitted

with triple-expansion engines, 500; position of cylinders, 500; steam-jackets, 501; cylinder ratios, 501; number of cranks, 501; calculation of twisting moments should include weight and momentum of moving parts, 502; progressive adoption of triple-expansion engines, 502; introduction of mild steel and corrugated boiler-flues, 502.—Cochrane, C., Enquiry respecting terminal pressure in low-pressure cylinder, 503.—Morison, D. B., Terminal pressure of 10 lbs. above perfect vacuum, equivalent to vacuum of 5 lbs. below atmosphere, 503.—Cochrane, C., Boiler duty should be separated from engine duty, 503; limit of steam velocity for full expansion without wire-drawing, 504.—Kennedy, A. B. W., Two-cylinder and three-cylinder compound engines, 504; size of ports, 504; want of exact experiments on marine-engine economy, 505; measurement of feed and circulating water, 505; calculation of steam consumption from indicator diagrams, 505; Table showing consumption of steam so calculated in two-cylinder and three-cylinder engines, 506; utilisation of higher pressure and greater expansion in three cylinders than in two, 508; relative inefficiency of low-pressure and high-pressure cylinder, 509; expanding of indicator diagrams from compound engines, 509.—Mudd, T., Conditions of efficiency in triple-expansion engines, 510; efficiency of steam and of mechanism, 510; five principal sources of loss in efficiency of steam, 511; triple-expansion engines of "Abeona," 511; comparison of actual with theoretical indicator diagrams, 512; sequence of cranks, 513; low-pressure crank leading, 513; high-pressure crank leading, 513; explanation of advantage in high-pressure crank leading, 514; oblique dividing lines between diagrams from triple-expansion engines, 514; three causes of advantage, 515; ranges of temperature in cylinders, 516; equality of initial stresses, and of horse-powers, 517; steam-jacketing more important for low-pressure cylinder, 517; cylinder ratios, 518; designing of steam-passages, 518; three cranks superior to two, 518; single-eccentric valve-gear, 518; Hackworth's valve-gear, 519.—Adamson, D., Practical value of triple-cylinder engine, 520; advantage of still higher boiler-pressure, 520; quadruple engine, 520; triple compound engines for stationary purposes, 520; range of temperature in cylinders, 521; steam-jacketing and superheating of steam between cylinders, 521; single-eccentric valve-gear, 522; Hackworth's valve-gear, 522; irregularities in indicator diagrams, 523; use of steel for steam boilers, 523; effect of temperature on strength of iron, 523; sequence of cylinders, and torsional strains on crank-shafts, 524; advantages of higher piston-speed in triple engines, 524.—Smith, R. H., Evaporating power of boilers, 524; greater efficiency of triple-expansion engines, 524; comparison of mechanical horse-power of boiler with indicated horse-power of engine, 525; conditions of efficiency in a triple engine, 526.—

Cochrane, C., Complete severance is wanted between performance of boiler and of engine, 526.—Crampton, T. R., Consumption of water per horse-power, 526; theoretical gain from high expansion is lost in friction &c., 527; locomotive with balanced cylinders neutralising strains, 527.—West, H. H., Range of temperature in cylinder should be considered in relation to stroke, 527.—Carbutt, E. H., Corrugated boiler-flues and saving in fuel, 528.—Greig, D., Three-cylinder and two-cylinder engines should be compared at same steam-pressure, 528; performance of boiler distinct from that of engine, 528; probability of higher steam-pressures, 529.—Scott-Moncrieff, W. D., Theoretical expansion curve for comparison with actual indicator diagrams, 529; interdependence between boiler and engine, 529.—Beaumont, W. W., Economy of fuel guides design of engines, 530; relative amounts of condensation in the several cylinders, 530.—Head, J., Adjournment of discussion, 531.

Tunnel Excavation, freezing of running ground, 236, 252, 259, 260. *See* Refrigerating Machinery.

Turner, A. H., decease, 4.—Memoir, 123.

Turner, G. R., elected Member, 2.

Turner, T., Remarks on Autographic Test-Recorder and Tests of Iron and Steel, 81, 84.

Turner, T. N., elected Member, 2.

Unwin, W. C., Remarks on Autographic Test-Recorder, 72, 77, 78, 79.

Urquhart, T., Remarks on Compound Locomotives, 390.

Valve-Gear, single-eccentric, 483, 518, 519, 522.

Vinçotte, R., Remarks on Compound Locomotives, 387.

Votes of Thanks, to Institution of Civil Engineers, 26, 127, 273 :—at Summer meeting, London, 273 :—to President for Address, 294.

Wailes, T. W., *Paper* on the Raising of the Wrecked Steamship "Peer of the Realm," 189.—Remarks on ditto, 194, 198.

Walker, B., re-elected Member of Council, 18.—Remarks on Autographic Test-Recorder, 70 :—on Hydraulic Buffer-Stop, 113 :—on Compound Locomotives, 398.

Walker, R. J., elected Graduate, 126.

Warham, J. R., memoir, 264.

Warren, F. L., elected Graduate, 2.

Weatherburn, R., elected Member, 271.

Wesley, J. A., elected Graduate, 2.

West, H. H., Remarks on Triple-Expansion Engines, 527.

Wheel Load in Cycles, *Paper* on the Distribution of the Wheel Load in Cycles, by J. A. Griffiths, 128.—Running resistances of cycle wheels, 128.—Classification of cycles, 129.—Efficiency of cycles, 130.—Five points of

efficiency, 131.—One-wheeled cycles, 132.—Two-wheeled cycles, 132.—Hobby horse, 132.—Front-driving bicycles, 132.—Distribution of weight in ordinary bicycle, 133.—Power of rider to vary distribution, 133.—Effect of brake on stability of bicycle, 134.—Safety bicycles, 134.—Rear-driving bicycles, 135.—Stability of rear-drivers when brake is applied to hind wheel, 136.—Kaiser safety bicycle with swinging seat-pillar, 137.—Relative stability of various kinds of bicycles, 137.—Speed of dwarf bicycles, 137.—Dicycles or broad-gauge bicycles, 138.—Three-wheeled cycles, 139.—Three-track tricycles:—class A, wheel-base triangle with apex aft, 139; front-drivers, single-driving, 139; double-driving, 140; stability increased by carrying the seat back, 141; rear-drivers, 141:—class B, wheel-base triangle with apex forwards, 142; Starley's balance-driving gear, 142; addition of fourth or guard wheel in rear, 142; perfect stability under action of brake, 142.—Two-track tricycles:—class C, wheel-base triangle with apex forwards laterally, 143:—class D, wheel-base triangle with apex symmetrical laterally, 144.—Cycles for two riders, 145.—One-track tandems, 145.—Tandem and sociable dicycles, 146.—Sociable and tandem tricycles, 146.—Four-wheeled cycles, 147.—Convertible sociable, 147.—Swivel coupling, 148.—Cycles with five or more wheels, 148.—Influence of gradient and of rider's position, 149.—Arrangements for varying rider's position, 149.—Sliding seats, and adjustable double frame, 150.—Automatic adjustment of rider's position, 151.—Spinaway tricycle with automatic adjustment of rider's position, 151; driving and carrying portion, 152; steering and braking apparatus, 152; load distribution, 153.—Kaiser cycles, with automatic adjustment of seats, 153.—Tabular analysis of gross and relative wheel-loads in thirty-nine examples, 154–161.

Discussion.—Griffiths, J. A., Recent progress in cycle manufacture, 162.—Boys, C. V., Introduction of word "dicycle," 163; classification of tricycles, 163; variation of load distribution according to the driving action, 164; dynamical considerations connected with treadle action and application of brake, 164; fore and aft stability of cycles, 166; effect of gyroscopic action of wheels on lateral stability of cycles, 167; steering of Otto dicycle, 168; want of efficient positive driving gear, 168; motion of seat in Spinaway and Kaiser cycles, 168.—Shaw, W. T., Variation of road resistance in relation to wheel diameter, 169; distribution of load in tricycles, 169; application of pressure to pedals and to brake, 170.—Boys, C. V., Effect of pedal pressure upon distribution of load, 170; effect of brake-action and of back-treadling, 170.—Marsland, L. W., Ease of riding Spinaway tricycle, 172.—Soper, W., Wheel load in relation to stability and rider's safety, and to ease of propulsion, 172; proper position for front wheel of bicycle, 173; triangle of stability, 173; resultant line of thrust when bicycle is in motion, 173; best form for tricycles, 174; Berkshire

tricycle, 174.—Stoney, F. G. M., Early four-wheeled velocipede, 175; twin cycle, 175; compound driver or positive clutch-gear, 175; advantages of ball bearings, 177; simple construction of ball bearing, 178; objection to curved surface of conical journal, 178.—Goodwin, A., Jun., Experience with ball bearings and roller bearings, 179; ball bearings for railway carriages, 179.—Paget, A., Application of ball bearings, 179; variation of road resistance in relation to wheel diameter, 180.—Shaw, W. T., Relation between rolling resistance and wheel diameter, 180.—Griffiths, J. A., Use of name "dicycle," 180; classification of tricycles, 180; variation of wheel load from dynamical considerations, 181; reduction of weight on rear-steering wheel in front-driving tricycles of class A, 181; distribution of rider's weight, 181; positive driving gear, 182; riding of Otto dicycle and of Spinaway tricycle, 182; variation of road resistance in relation to wheel diameter, 182; height of rider's centre of gravity, 182; triangle of stability, 183; clutch-driving and balance-driving gear, 183; wear of cones and of cases for ball bearings, 184; disadvantages of long bearings, 184; ball bearings for railway carriages, 185.—Head, J., Cycles worthy of attention by mechanical engineers, 185; good roads essential, 186; cycle ways, 186; danger of ordinary bicycle, 186; wheel-gauge of tricycles, 187; sociables preferable to tandems, 187.

Wicksteed, J. H., re-elected Member of Council, 18.—*Paper* on an Autographic Test-Recording Apparatus, 27.—Remarks on ditto, and on Tests of Iron and Steel, 62, 69, 77, 78, 79, 86, 93, 94, 101.

Wicksteed's Autographic Test-Recorder, 27. *See* Autographic Test-Recorder.

Wildridge, J., elected Member, 2.

Williams, E., memoir, 264.

Willmott, A. W. W., memoir, 265.

Wilmer, H., Remarks on Hydraulic Buffer-Stop, 116.

Windsor, E. W., elected Member, 465.

Wolff, H. M., elected Member, 2.

Wood, T., memoir, 463.

Woolwich Arsenal, visited at Summer meeting, London, 411, 440–441.

Works visited at Summer meeting, London, 410–459.

Worsdell, T. W., elected Member of Council, 18.

Worthington, C. C., elected Member, 126.

Wreck-Raising, 189. *See* Raising a Wreck.

Wylie, J., elected Member, 126.

Wyllie, R., memoir, 464.—*Paper* on Triple-Expansion Marine Engines, 473.

Yarrow and Co.'s Works, Poplar, visited at Summer meeting, London, 412, 457.

Yorkshire College, Leeds, Opening of Engineering Department by President at Autumn meeting, 468.

"Para."
Scale 1/48th.

Fig. 1.
End
Elevation.

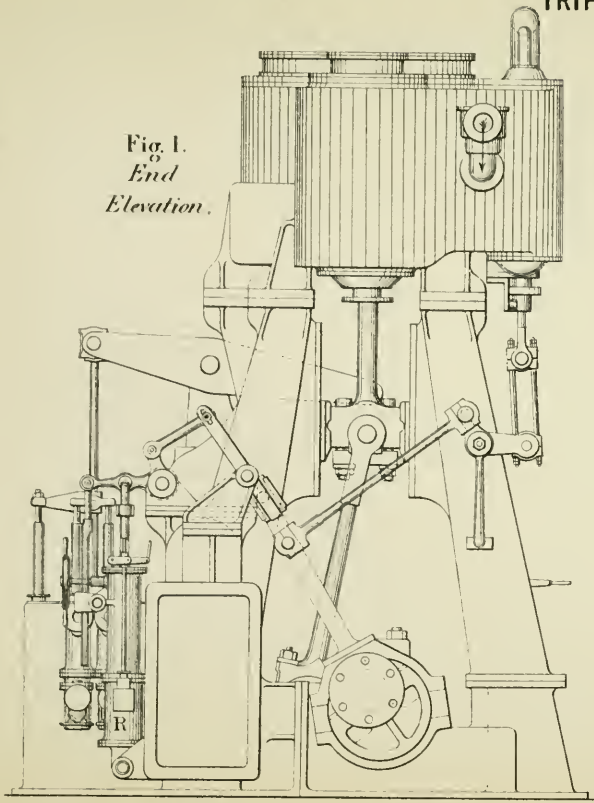
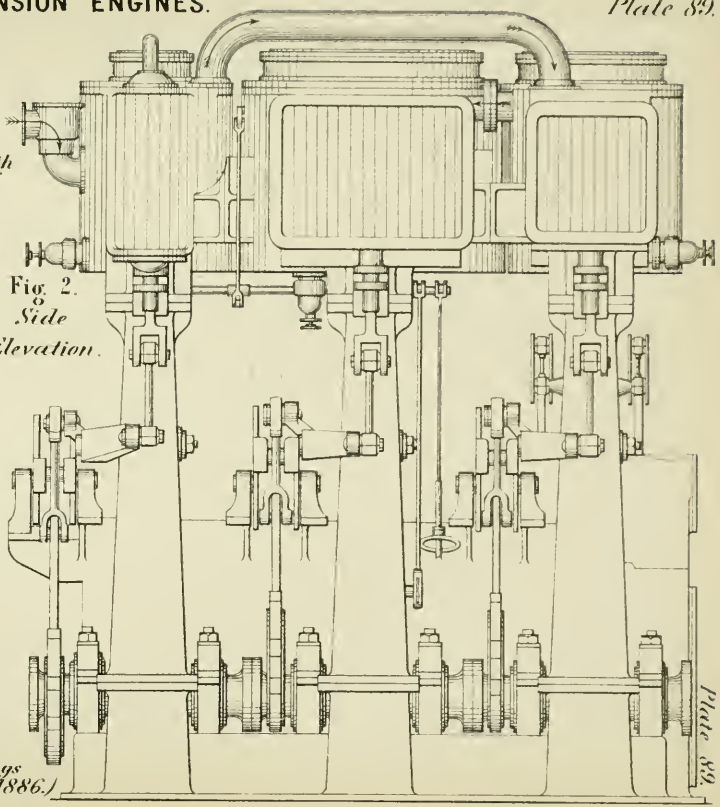


Fig. 2.
Side
Elevation.



(Proceedings Inst. M.E. 1886.)

Plate 89.

"African"
and
"Shakespear."

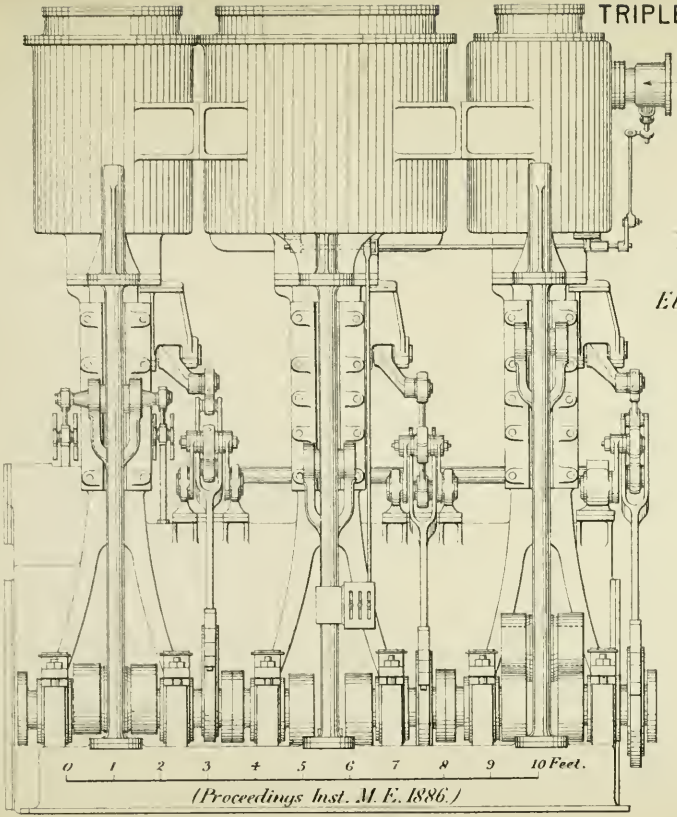


Fig. 3.
Side
Elevation

Scale 1/48th

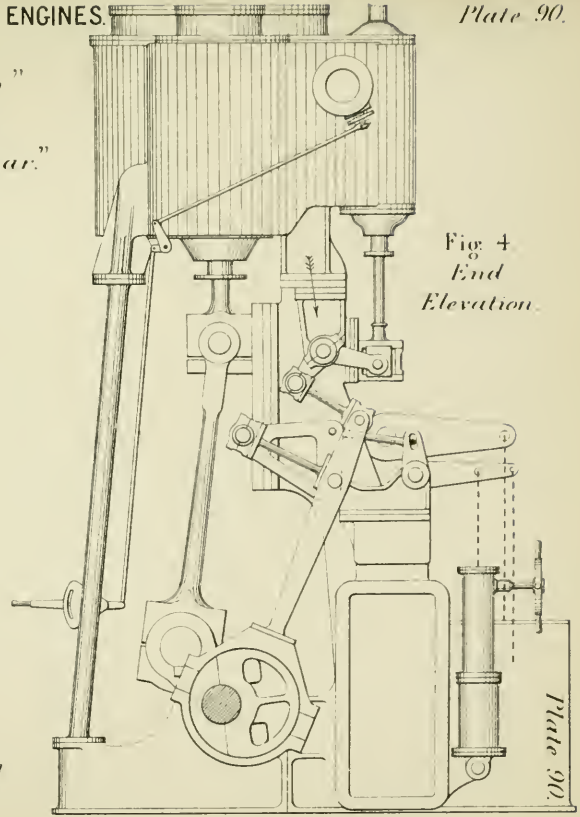
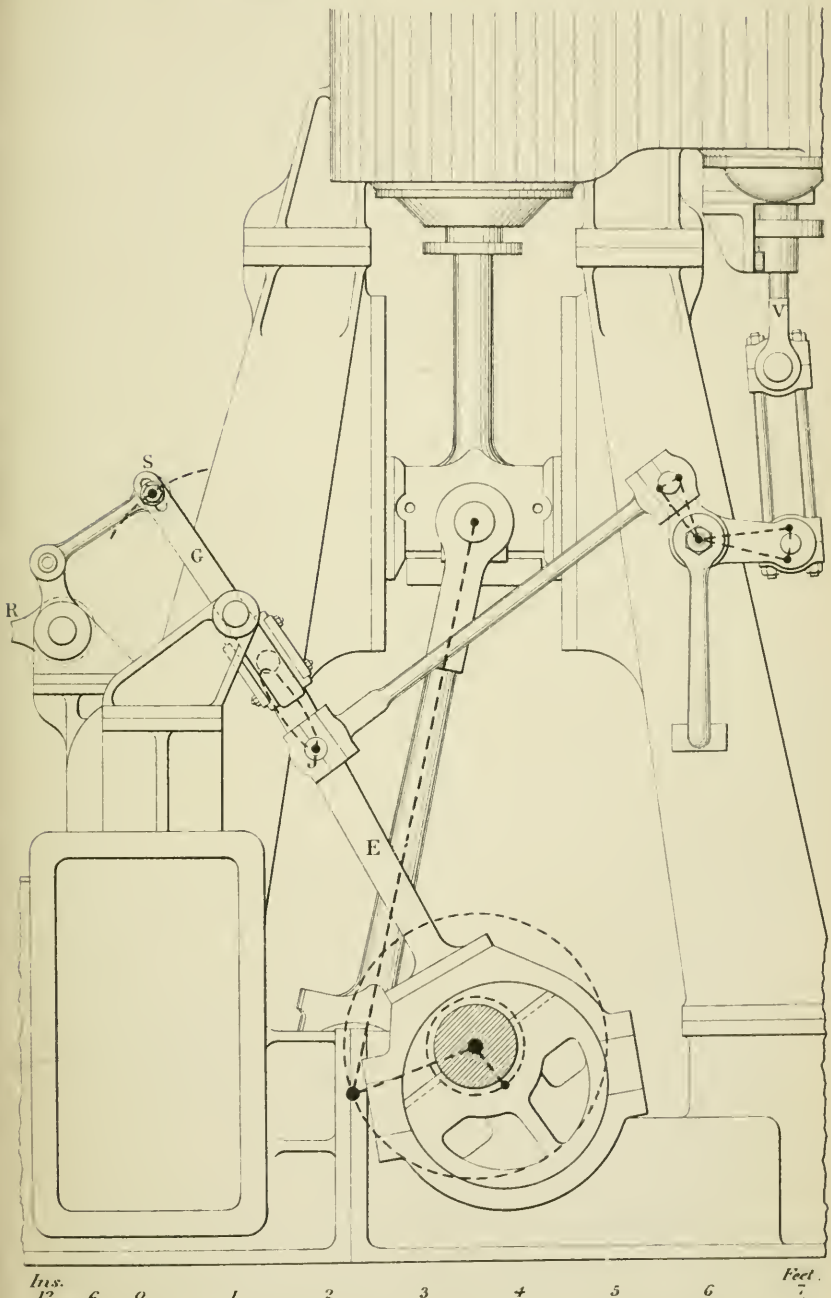


Fig. 4
End
Elevation.

(Proceedings Inst. M.E. 1886.)

Plate 90.

Fig 5. *Elevation of Sliding-Block Valve-Gear.*



(Proceedings Inst. M. E. 1886.)

Scale 1/24th

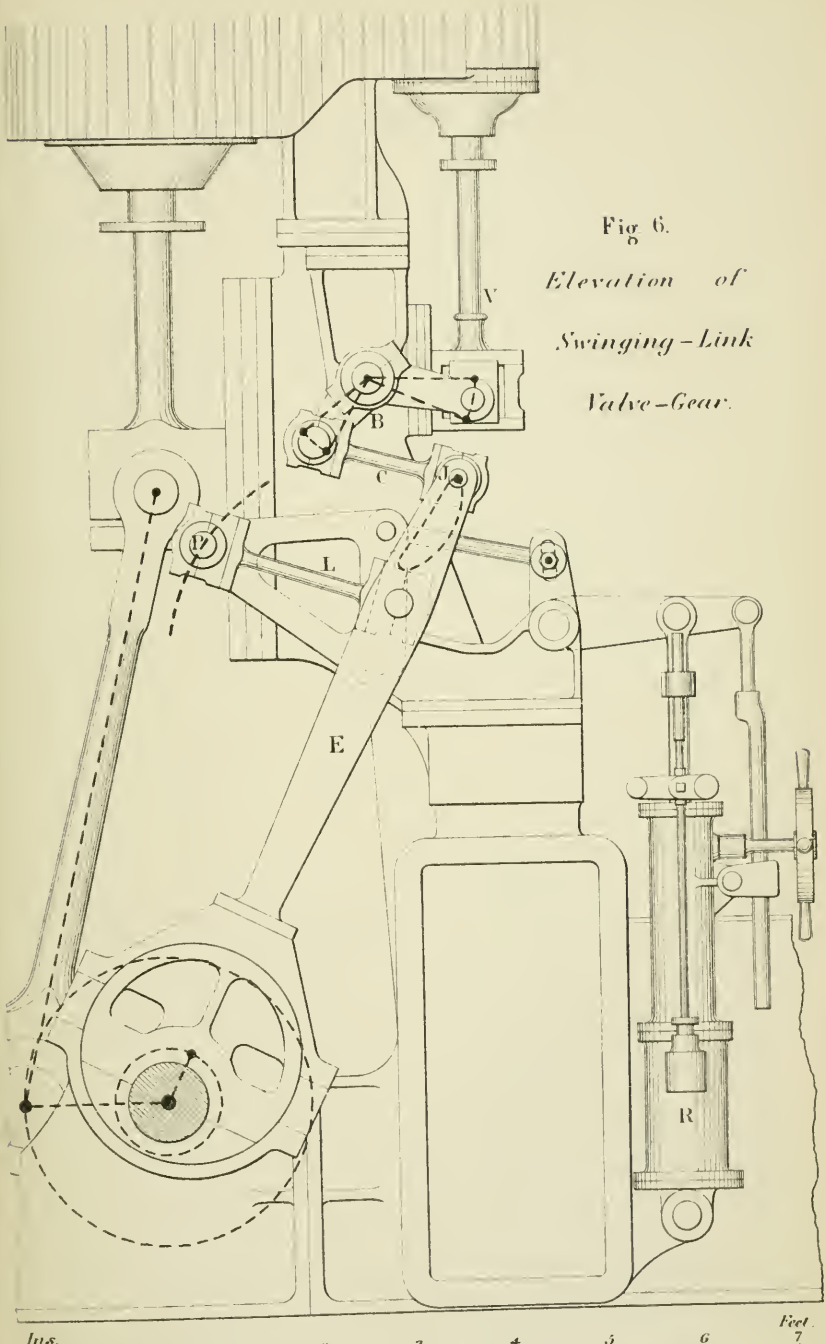


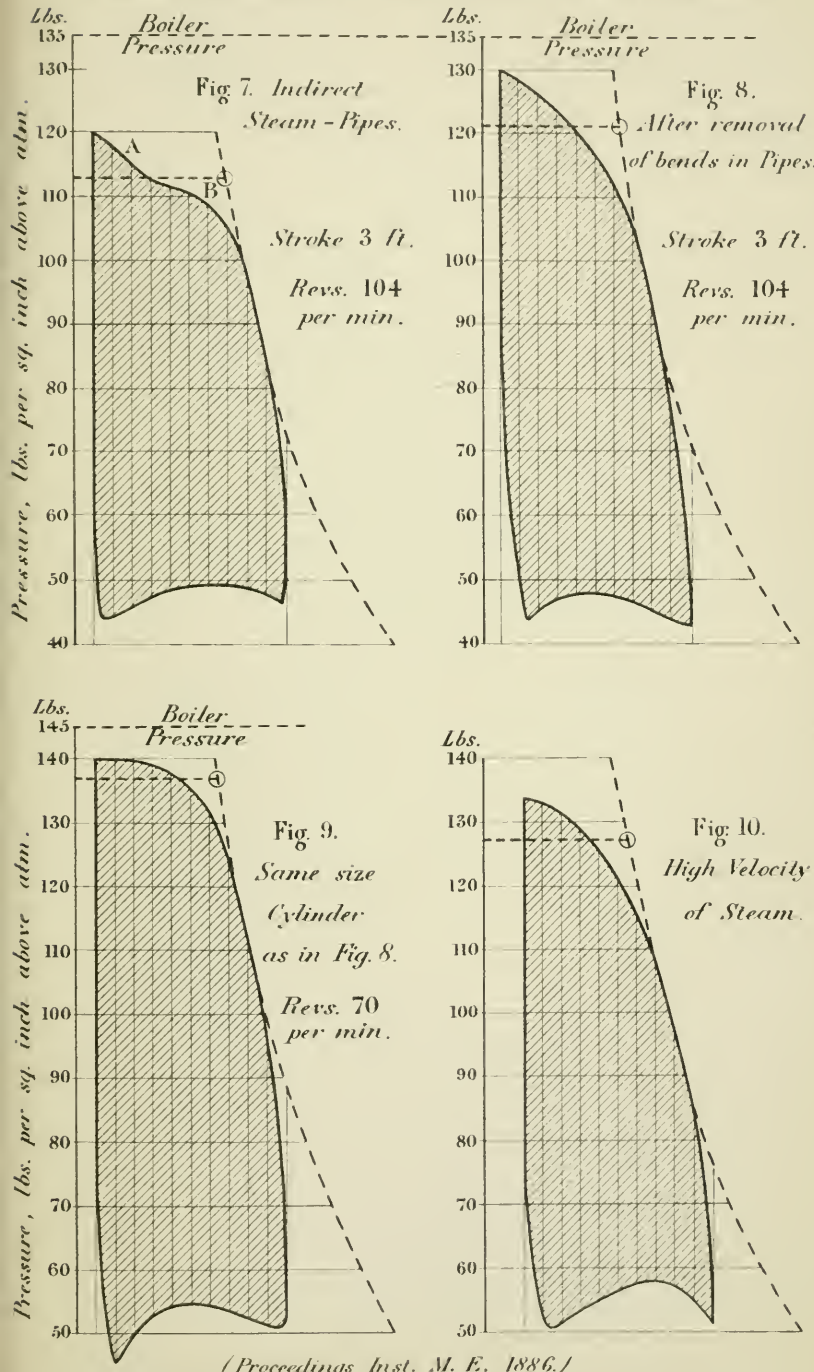
Fig 6.

Elevation of Swinging-Link Valve-Gear.

Scale 1/24th

(Proceedings Inst M.E. 1886.)

Indicator Diagrams from High-Pressure Cylinders.



(Proceedings Inst. M. E. 1886.)

Indicator Diagrams from Intermediate Cylinders.

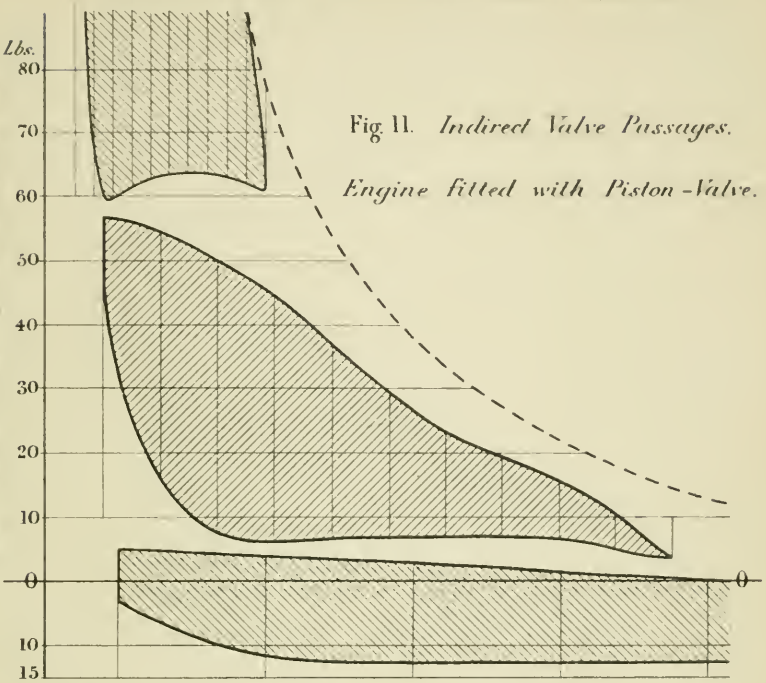


Fig. 11. *Indirect Valve Passages.*

Engine fitted with Piston-Valve.

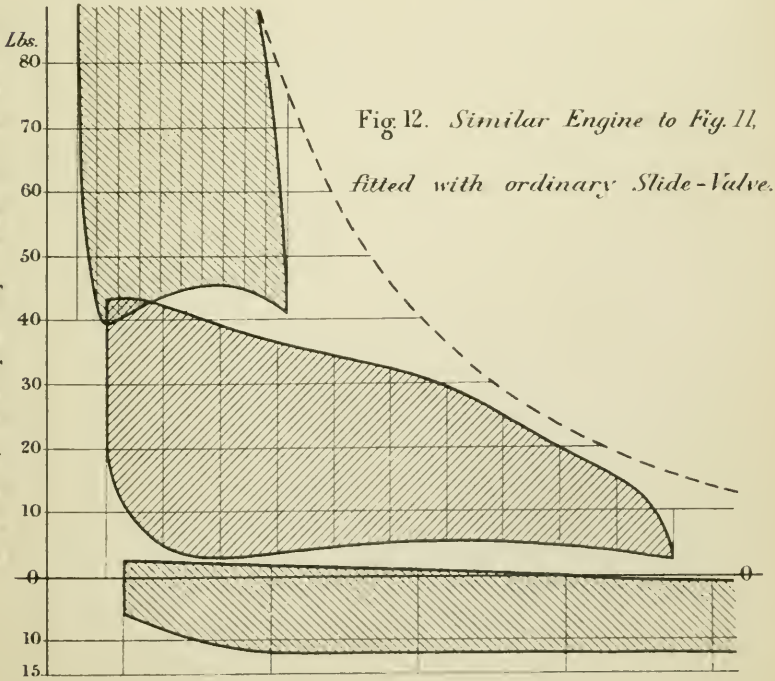


Fig. 12. *Similar Engine to Fig. 11,*

fitted with ordinary Slide-Valve.

(*Proceedings Inst. M. E. 1886.*)

Indicator Diagrams from Intermediate Cylinders.

Fig. 13. *High Steam Velocity. Light-ship trial.*

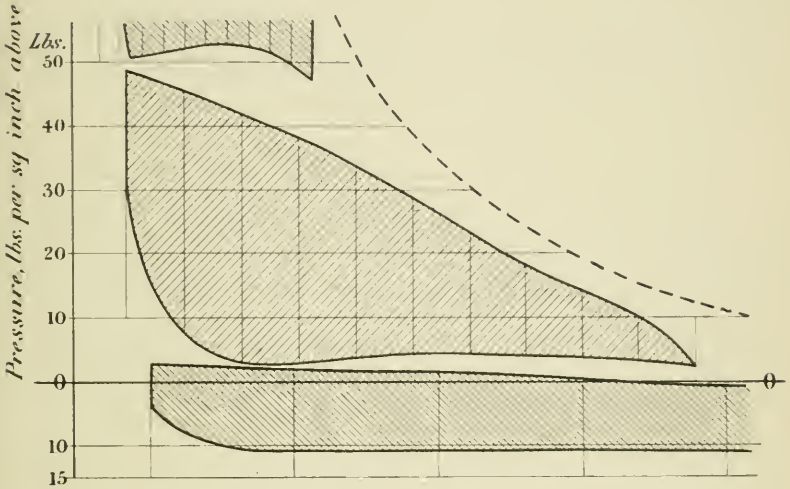
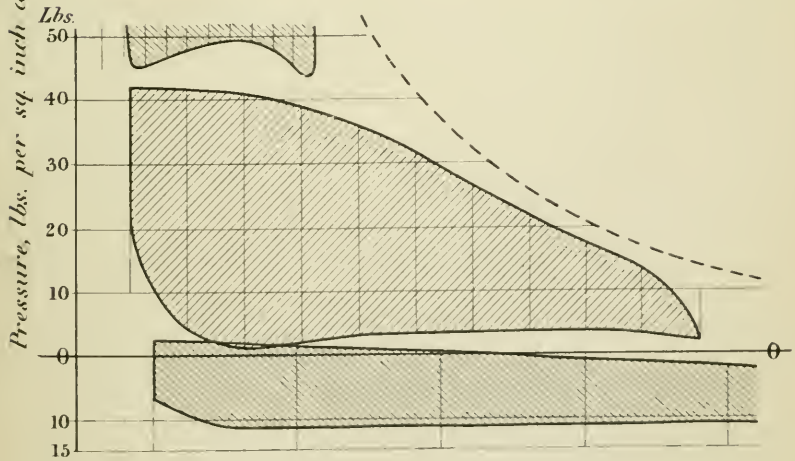


Fig. 14. *Same Cylinder as Fig. 13. Loaded ship.*



(Proceedings Inst. M. E. 1886.)

Indicator Diagrams from Low-Pressure Cylinder.

Excessive exhaust velocity.

Fig. 15. *Revs. 68 per min.*

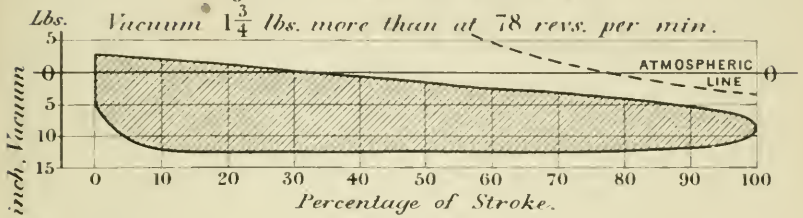


Fig. 16. *Revs. 78 per min.*

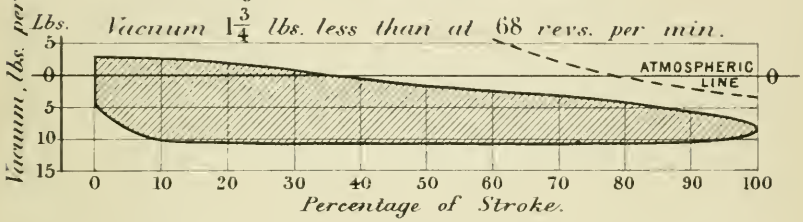
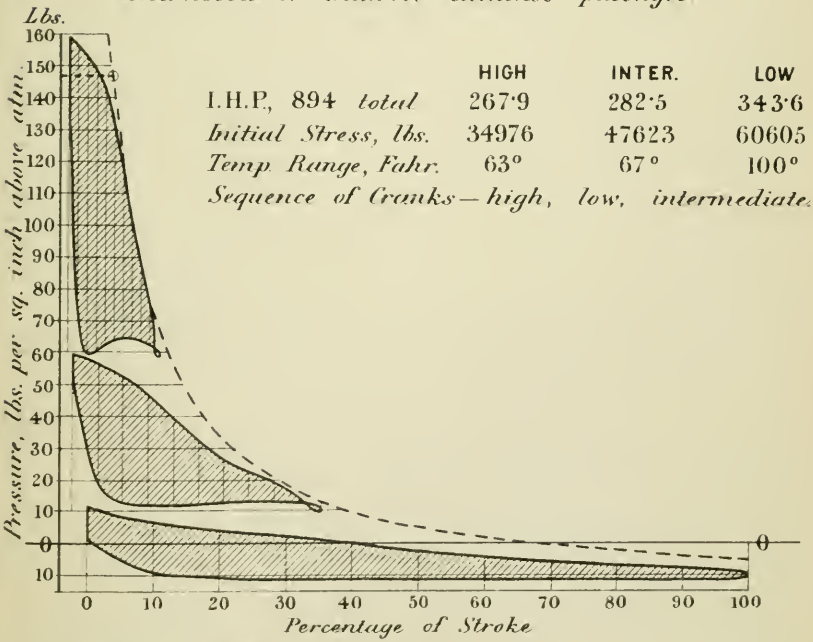


Fig. 17. *Combined Diagrams from Three Cylinders.*

Contracted or indirect exhaust passages.



	HIGH	INTER.	LOW
I.H.P., 894 *total*	267·9	282·5	343·6
Initial Stress, lbs.	34976	47623	60605
Temp. Range, Fahr.	63°	67°	100°

Sequence of Cranks—high, low, intermediate.

(Proceedings Inst. M. E. 1886.)

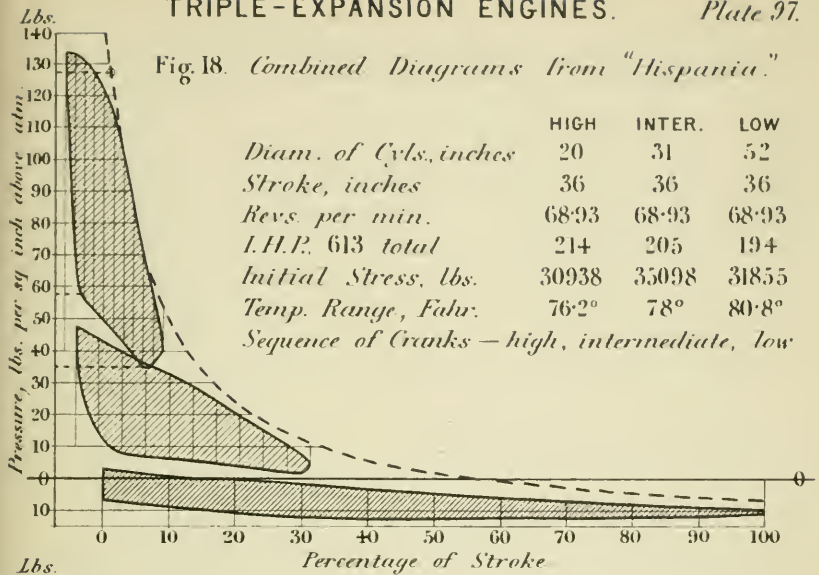


Fig. 18. *Combined Diagrams from "Hispania."*

	HIGH	INTER.	LOW
Diam. of Cyls., inches	20	31	52
Stroke, inches	36	36	36
Revs. per min.	68·93	68·93	68·93
I.H.P. 613 total	214	205	194
Initial Stress, lbs.	30938	35098	31855
Temp. Range, Fahr.	76·2°	78°	80·8°

Sequence of Cranks — high, intermediate, low

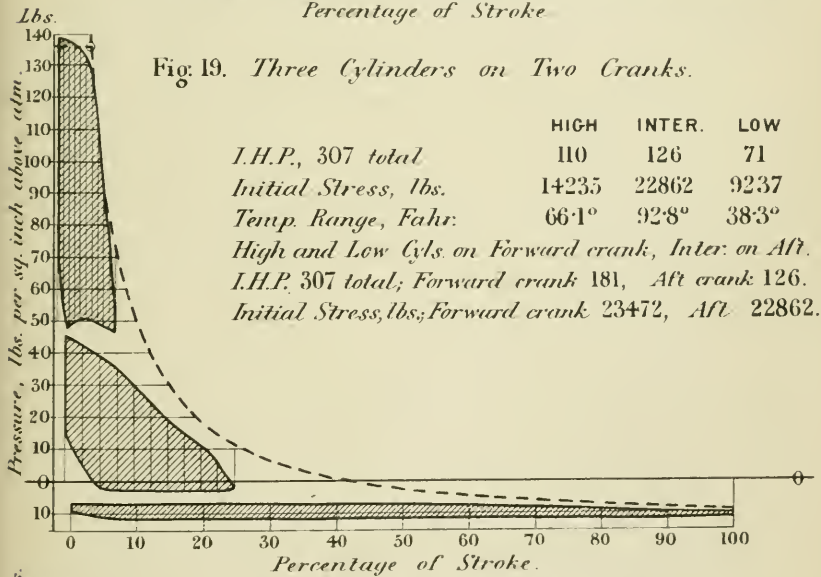


Fig. 19. *Three Cylinders on Two Cranks.*

	HIGH	INTER.	LOW
I.H.P., 307 total	110	126	71
Initial Stress, lbs.	14235	22862	9237
Temp. Range, Fahr.	66·1°	92·8°	38·3°

High and Low Cyls. on Forward crank, Inter. on Aft.
I.H.P. 307 total; Forward crank 181, Aft crank 126.
Initial Stress, lbs; Forward crank 23472, Aft 22862.

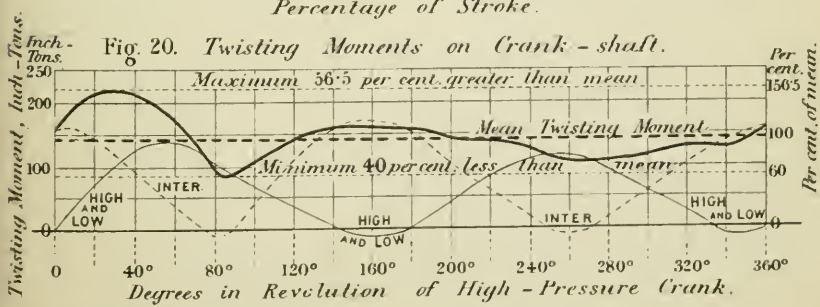


Fig. 20. *Twisting Moments on Crank-shaft.*

(Proceedings Inst. M.E. 1886.)

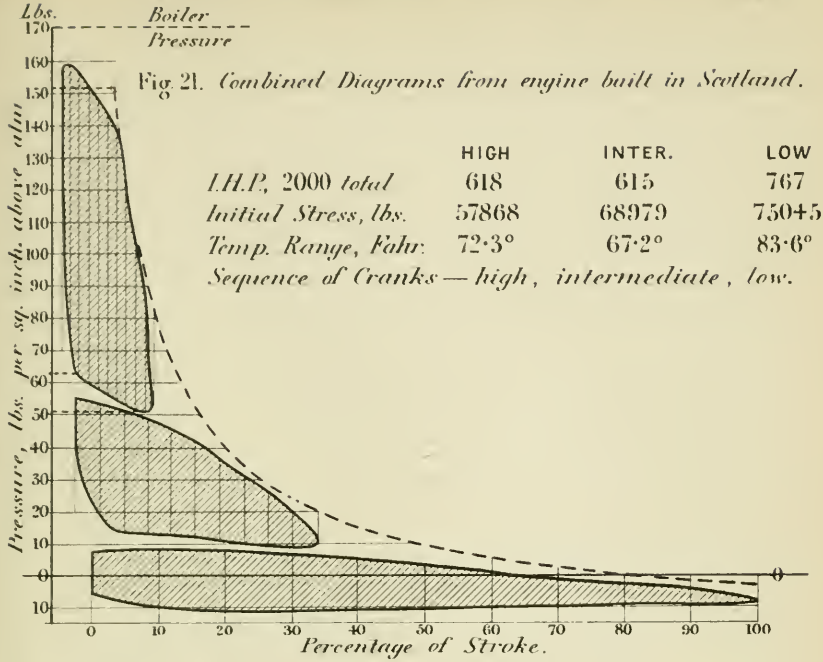


Fig. 21. *Combined Diagrams from engine built in Scotland.*

	HIGH	INTER.	LOW
I.H.P. 2000 *total*	618	615	767
Initial Stress, lbs.	57868	68979	75045
Temp. Range, Fahr.	72·3°	67·2°	83·6°

Sequence of Cranks — high, intermediate, low.

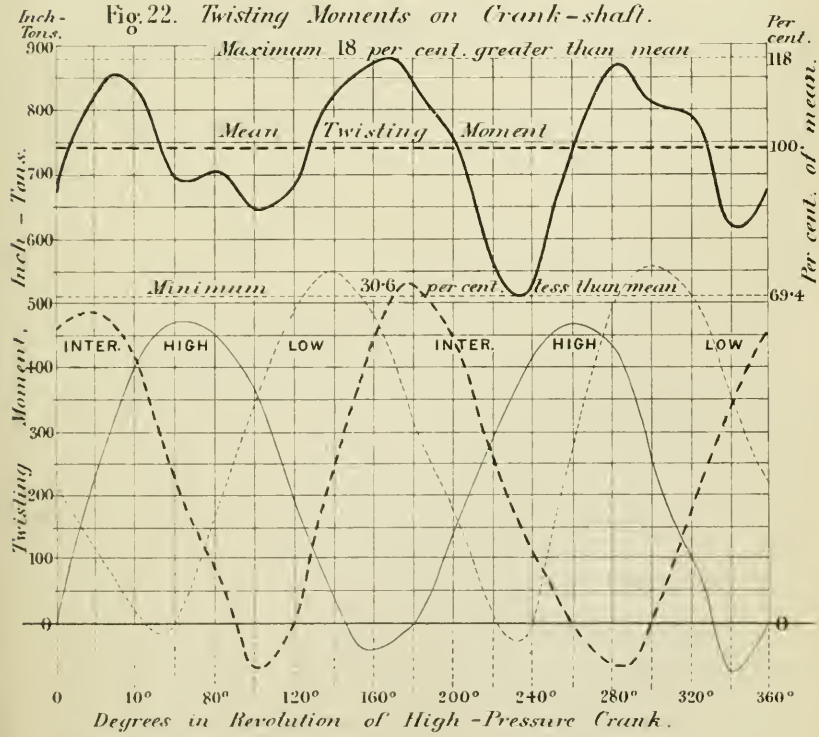
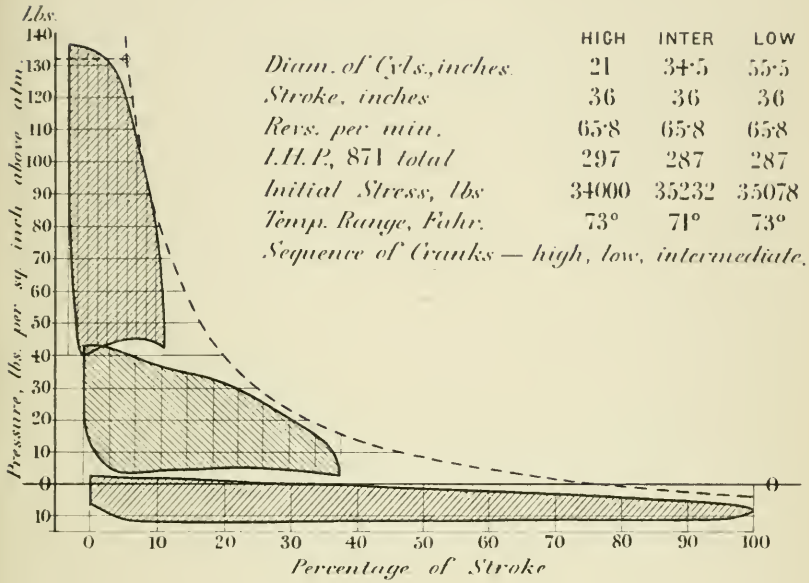


Fig. 22. *Twisting Moments on Crank-shaft.*

(Proceedings Inst. M.E. 1886.)

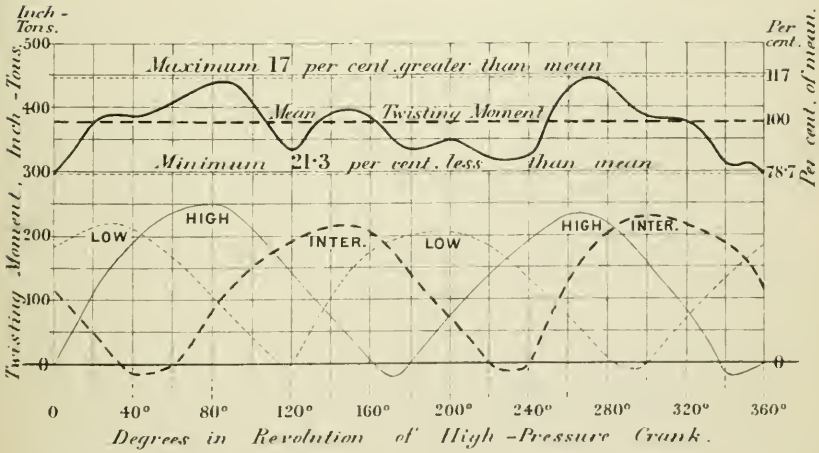
Fig 23. *Combined Diagrams from "Shakespear."*



	HIGH	INTER	LOW
Diam. of Cyls., inches	21	34·5	55·5
Stroke, inches	36	36	36
Revs. per min.	65·8	65·8	65·8
I.H.P., 871 total	297	287	287
Initial Stress, lbs	34000	35232	35078
Temp. Range, Fahr.	73°	71°	73°

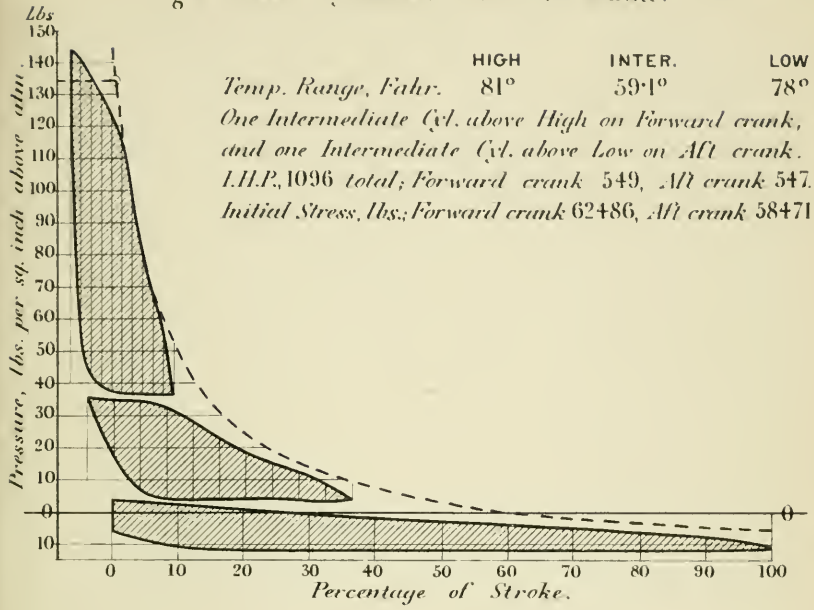
Sequence of Cranks — high, low, intermediate.

Fig 24. *Twisting Moments on Crank-shaft.*



[Proceedings Inst. M.E. 1886.]

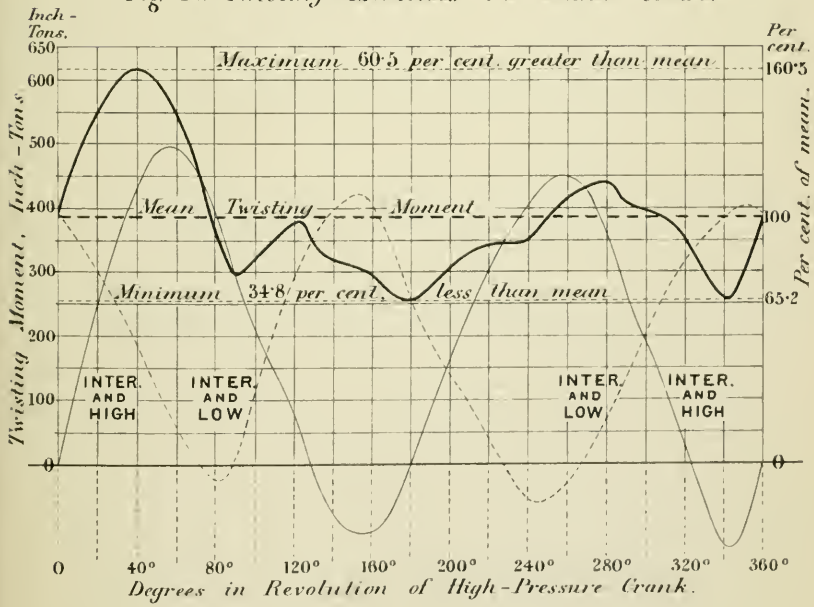
Fig. 25. *Four Cylinders on Two Cranks.*



	HIGH	INTER.	LOW
Temp. Range, Fahr.	81°	59·1°	78°

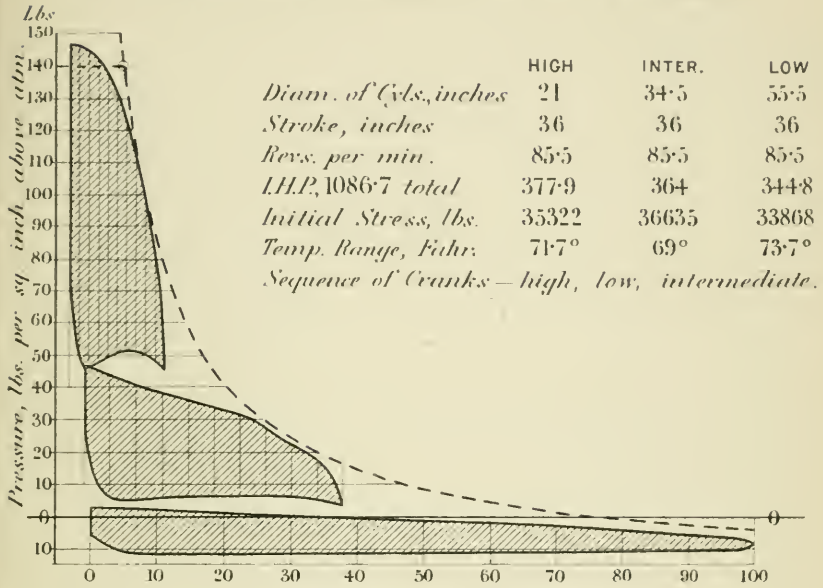
One Intermediate Cyl. above High on Forward crank, and one Intermediate Cyl. above Low on Aft crank.
I.H.P., 1096 *total*; *Forward crank* 549, *Aft crank* 547.
Initial Stress, lbs.; *Forward crank* 62486, *Aft crank* 58471.

Fig. 26. *Twisting Moments on Crank-shaft.*



(Proceedings Inst. M. E. 1886.)

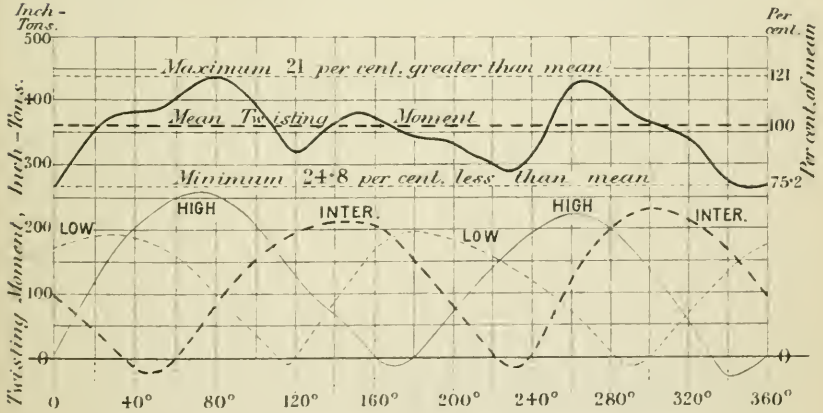
Fig. 27. *Combined Diagrams from "African."*



	HIGH	INTER.	LOW
Diam. of Cyls., inches	21	34·5	55·5
Stroke, inches	36	36	36
Revs. per min.	85·5	85·5	85·5
I.H.P., 1086·7 total	377·9	364	344·8
Initial Stress, lbs.	35322	36635	33868
Temp. Range, Fahr.	71·7°	69°	73·7°

Sequence of Cranks — high, low, intermediate.

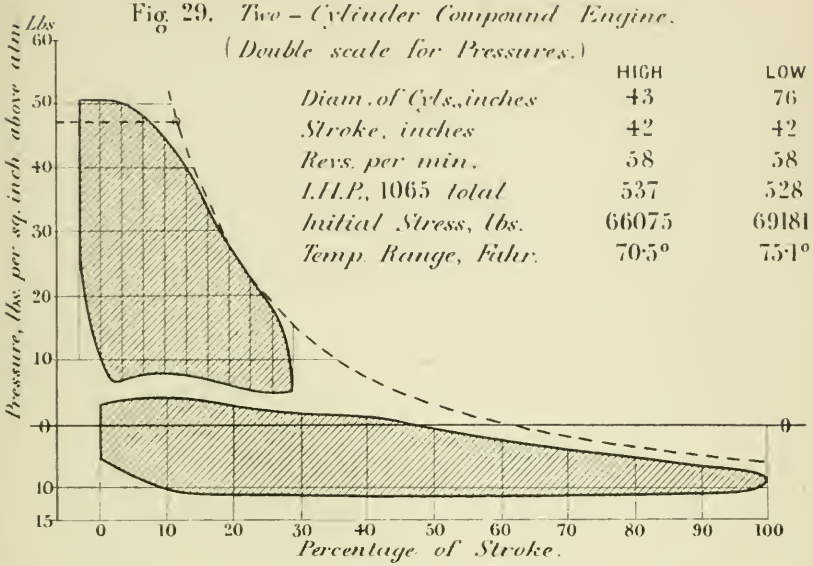
Fig. 28. *Twisting Moments on Crank-shaft.*



Combined Diagrams from "Anglian."

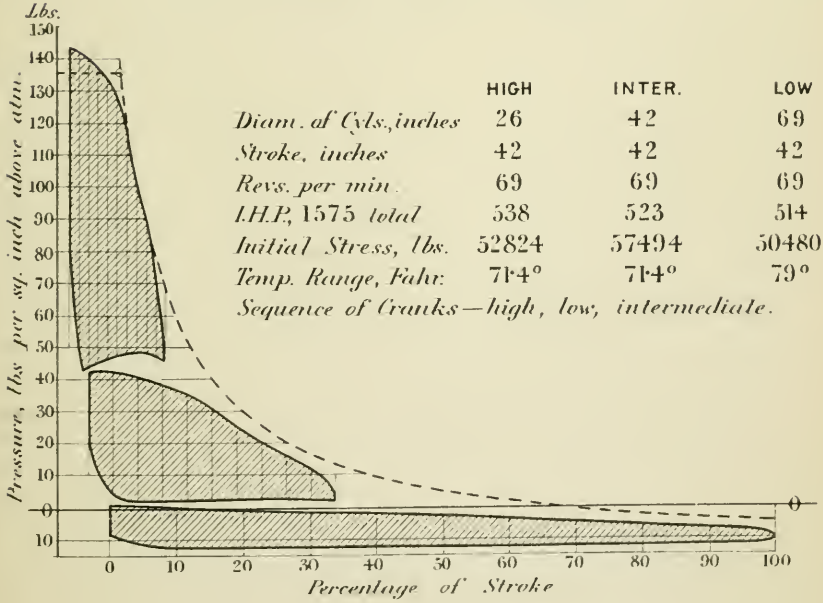
Fig. 29. *Two-Cylinder Compound Engine.*

(Double scale for Pressures.)



	HIGH	LOW
Diam. of Cyls., inches	43	76
Stroke, inches	42	42
Revs. per min.	58	58
I.H.P., 1065 total	537	528
Initial Stress, lbs.	66075	69181
Temp. Range, Fahr.	70·5°	75·1°

Fig. 30. *Triple-Expansion Engine.*



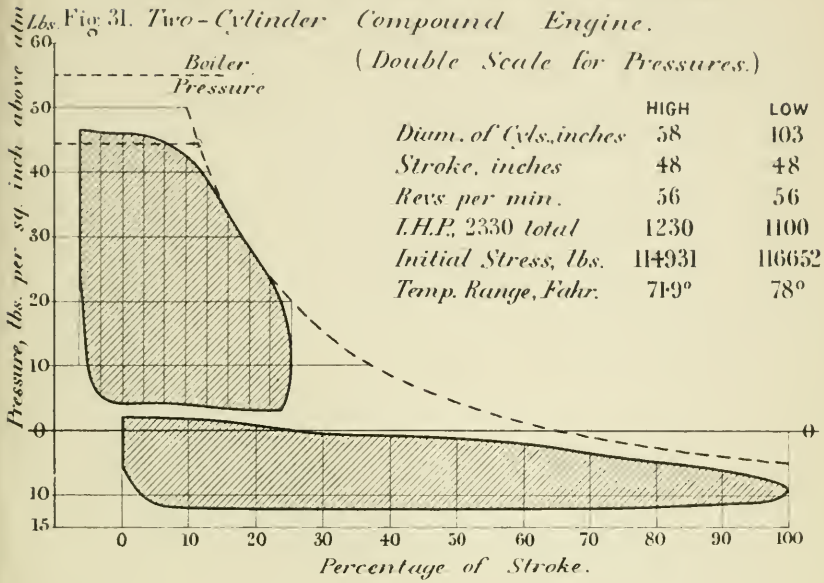
	HIGH	INTER.	LOW
Diam. of Cyls., inches	26	42	69
Stroke, inches	42	42	42
Revs. per min.	69	69	69
I.H.P., 1575 total	538	523	514
Initial Stress, lbs.	52824	57494	50480
Temp. Range, Fahr.	71·4°	71·4°	79°

Sequence of Cranks—high, low, intermediate.

(Proceedings Inst. M.E. 1886.)

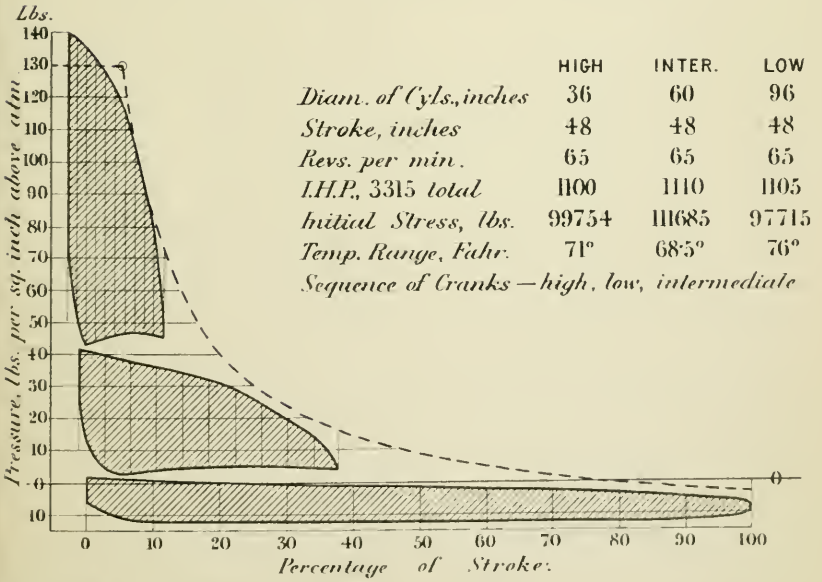
Combined Diagrams from "Lusitania."

Fig. 31. *Two-Cylinder Compound Engine.* (*Double Scale for Pressures.*)



	HIGH	LOW
Diam. of Cyls., inches	58	103
Stroke, inches	48	48
Revs per min.	56	56
I.H.P., 2330 total	1230	1100
Initial Stress, lbs.	114931	116652
Temp. Range, Fahr.	71·9°	78°

Fig. 32. *Triple-Expansion Engine.*

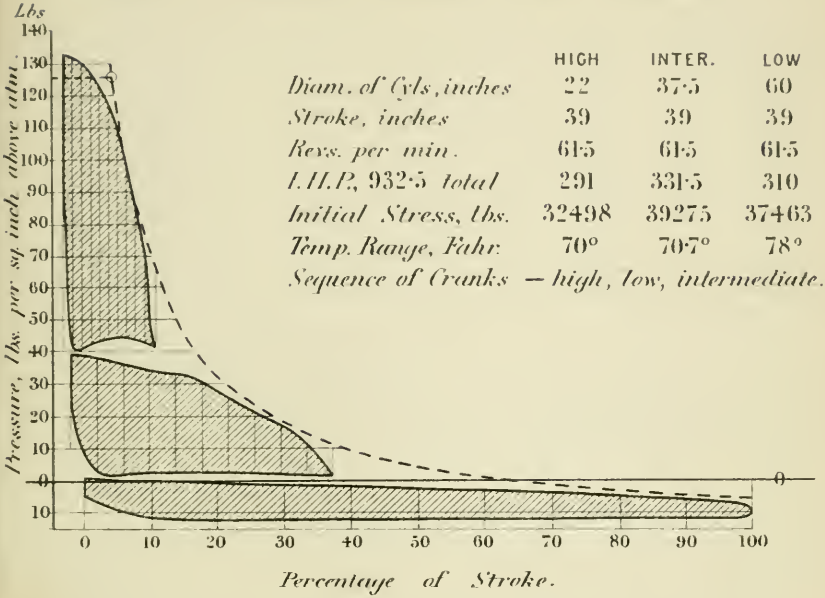


	HIGH	INTER.	LOW
Diam. of Cyls., inches	36	60	96
Stroke, inches	48	48	48
Revs. per min.	65	65	65
I.H.P., 3315 total	1100	1110	1105
Initial Stress, lbs.	99754	111685	97715
Temp. Range, Fahr.	71°	68·5°	76°

Sequence of Cranks — high, low, intermediate

(Proceedings Inst. M. E., 1886.)

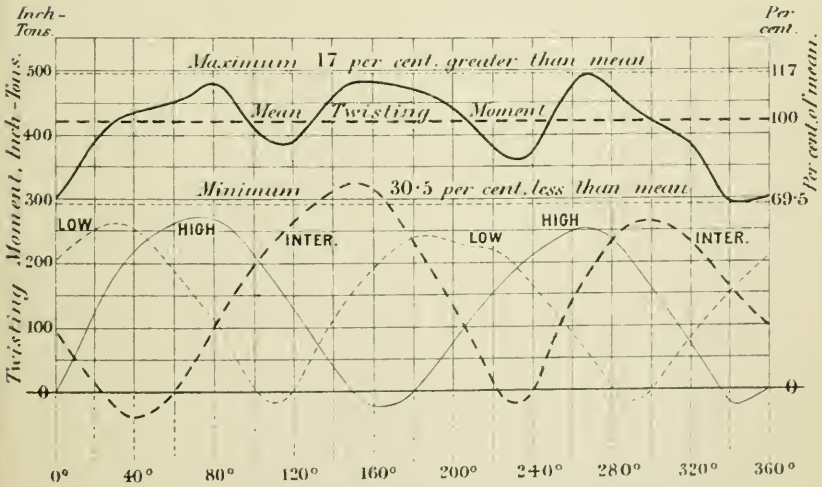
Fig 33. *Combined Diagrams from "Stella"*



	HIGH	INTER.	LOW
Diam. of Cyls, inches	22	37·5	60
Stroke, inches	39	39	39
Revs. per min.	61·5	61·5	61·5
I.H.P., 932·5 total	291	331·5	310
Initial Stress, lbs.	32498	39275	37463
Temp. Range, Fahr.	70°	70·7°	78°

Sequence of Cranks — high, low, intermediate.

Fig 34. *Twisting Moments on Crank-shaft.*



(Proceedings Inst. M. E. 1886.)

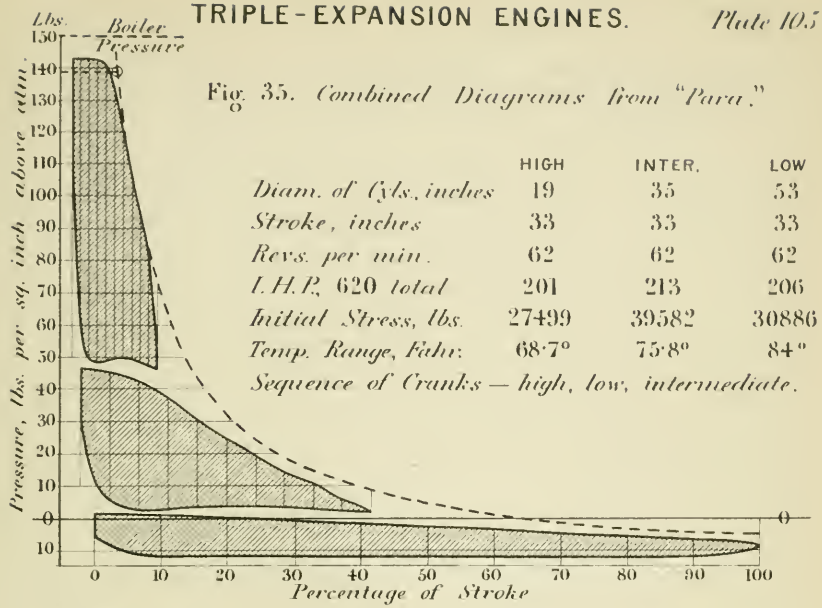


Fig. 35. *Combined Diagrams from "Para."*

	HIGH	INTER.	LOW
Diam. of Cyls., inches	19	35	53
Stroke, inches	33	33	33
Revs. per min.	62	62	62
I.H.P. 620 total	201	213	206
Initial Stress, lbs.	27499	39582	30886
Temp. Range, Fahr.	68·7°	75·8°	84°

Sequence of Cranks — high, low, intermediate.

Artificial Draught for Marine Boilers.

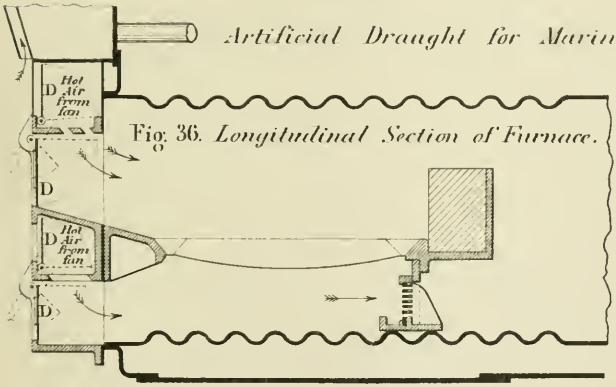


Fig. 36. *Longitudinal Section of Furnace.*

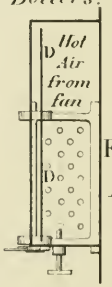


Fig. 37. *Plan.*

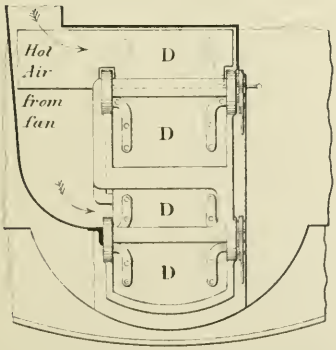


Fig. 38. *Front Elevation.*

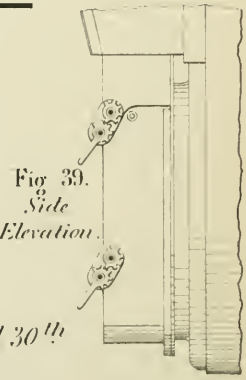


Fig. 39. *Side Elevation.*

Scale 1 30th

(Proceedings Inst. M.E. 1886.)

Ins. 12 6 0 1 2 3 4 Feet

Artificial Draught for Marine Boilers.

Fig. 40. *Front Elevation*

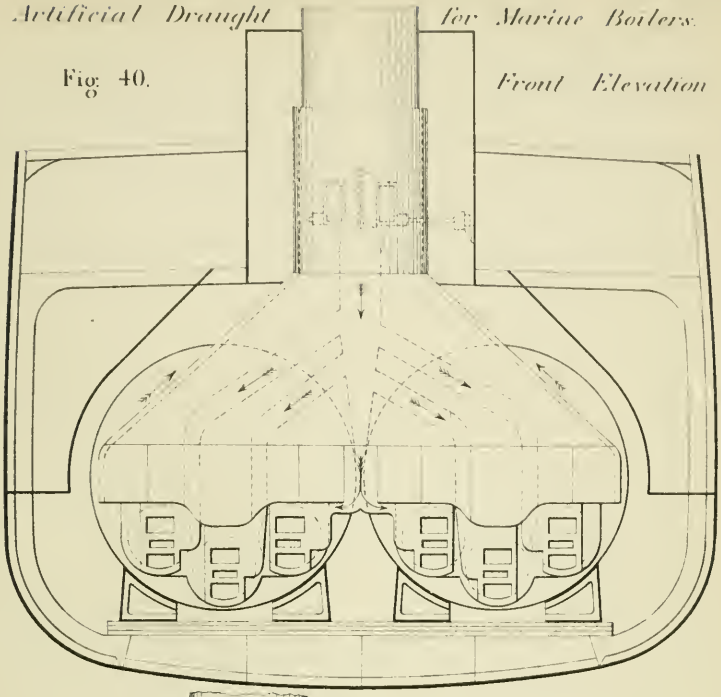
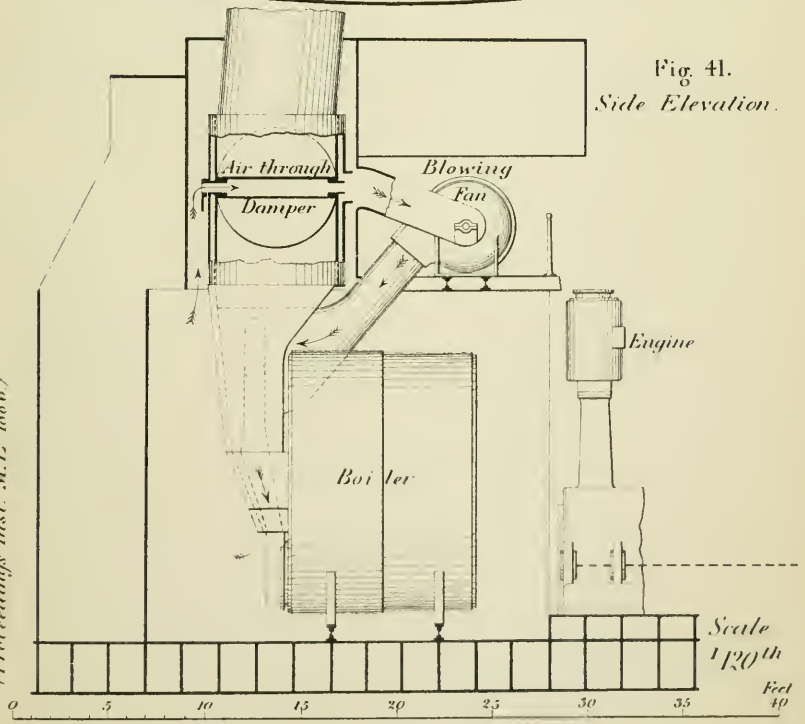


Fig. 41. *Side Elevation.*



(Proceedings Inst. M.E. 1886.)

Indicator Diagrams from "Abeona".

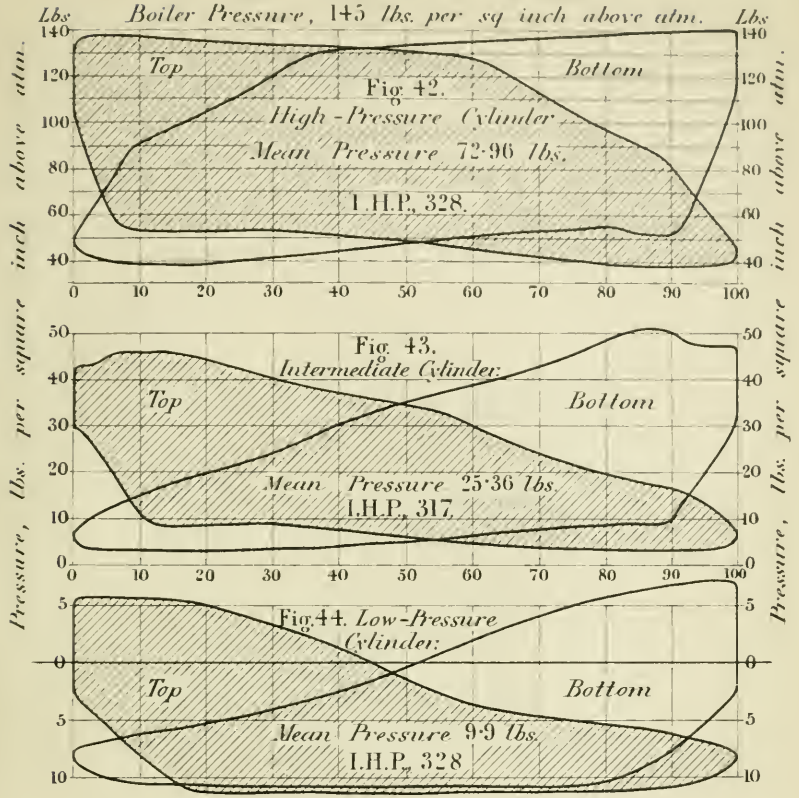
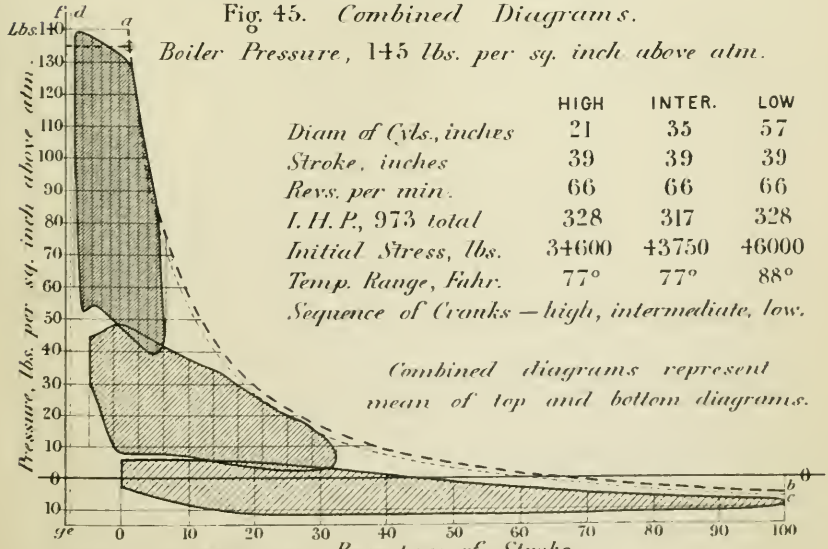


Fig. 45. *Combined Diagrams.*

Boiler Pressure, 145 lbs. per sq. inch above atm.



	HIGH	INTER.	LOW
Diam of Cyls., inches	21	35	57
Stroke, inches	39	39	39
Revs. per min.	66	66	66
I.H.P., 973 total	328	317	328
Initial Stress, lbs.	34600	43750	46000
Temp. Range, Fahr.	77°	77°	88°

Sequence of Cranks — high, intermediate, low.

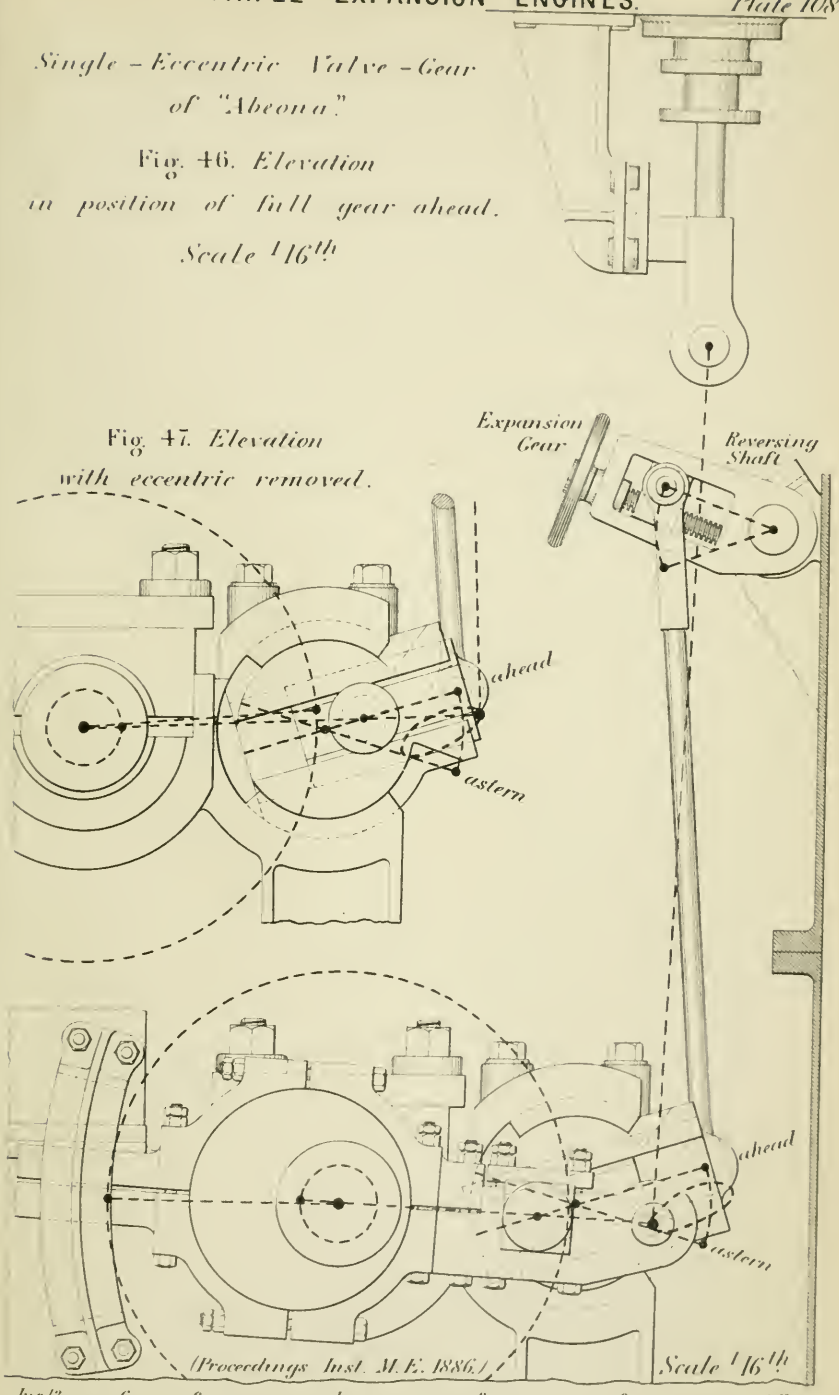
Combined diagrams represent mean of top and bottom diagrams.

(Proceedings Inst. M.E. 1886.)

Single-Eccentric Valve-Gear of "Abeona."

Fig. 46. *Elevation in position of full gear ahead.*
Scale 1/16th.

Fig. 47. *Elevation with eccentric removed.*



TJ
1
I4
1886

Institution of Mechanical Engineers, London
Proceedings

[redacted]
Physical &
Applied Sci.
Serials

Engineering

PLEASE DO NOT REMOVE
CARDS OR SLIPS FROM THIS POCKET

UNIVERSITY OF TORONTO LIBRARY

ENGIN STORAGE